# WORK PLAN FOR SITE CHARACTERIZATION
# AREA OF INTEREST 8

# SUNOCO PHILADELPHIA REFINERY
# PHILADELPHIA, PENNSYLVANIA

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# TABLE OF CONTENTS

## LIST OF TABLES



## LIST OF FIGURES



## LIST OF APPENDICES

## 1.0 INTRODUCTION

The Current Conditions Report and Comprehensive Remedial Plan (CCR) prepared by Sunoco Inc. (R&M) (Sunoco), dated June 30, 2004, proposed Phase II site characterization and corrective action activities for Sunoco's Philadelphia Refinery (Refinery), including preparation of Site Characterization Reports for individual Areas of Interest (AOIs). The CCR presented a prioritization of all eleven AOIs based on specific risk factors. To date, site characterization activities have been completed for four AOIs at the Refinery. These include AOI 1 (Belmont Terminal, #1 Tank Farm and #2 Tank Farm), AOI 4 (#4 Tank Farm), AOI 6 (Girard Point Chemicals Processing Area), and AOI 5 (Girard Point South Tank Field Area). Site characterization work plans and site characterization reports for these four AOIs were submitted to the Pennsylvania Department of Environment Protection (PADEP) and the United States Environmental Protection Agency (US EPA).

This site characterization work plan (work plan) has been prepared specifically for AOI 8, the next AOI to be characterized in accordance with the revised Phase II Corrective Action Schedule which is included as Appendix A.

AOI 8 is the northern most area of the Refinery and is known as the Point Breeze Process Area North Yard. AOI 8 is bound by the Philadelphia Gas Works (PGW) plant to the south, the Schuylkill River to the west, industrial properties to the north, and urban streets to the east (Figure 1). AOI 8 encompasses approximately 250 acres.

The North Yard was an active Refinery process area since the early twentieth century with significant process areas and above ground storage tanks (ASTs). The north yard also included the former lube, asphalt, soap, and wax plants. The majority of AOI 8 structures were demolished between 1975 and 1980. Subsequent to decommissioning of most of the process areas, a Land Treatment Unit ("LTU") was operated from 1986 through 2000. Currently, the only remaining active facilities in AOI 8 are the asphalt dock, the boiler house, a storm water separator, fuel oil storage, butane and propane storage area, and loading and unloading facilities. Much of AOI 8 is unoccupied and many of the ASTs have been demolished. The majority of the land surface in AOI 8 is not covered by impervious surfaces.

The existing monitoring well network in AOI 8 includes a total of 95 monitoring wells, 13 piezometers, and 20 recovery wells. Of the 20 recovery wells, nine are active. These nine active recovery wells are associated with three remedial systems; they include the the PGW Border Total Fluids Recovery System, the Jackson Street Sewer Total Fluids Recovery System, and the North Yard Bulkhead / No. 3 Tank Farm Separator Total Fluids Recovery System. These remedial systems are discussed in detail in Section 1.3 of this Work Plan.

Ground water gauging of selected wells in AOI 8 occurs on a quarterly basis and is supplemented by a more comprehensive gauging event that is completed semi-annually. Sunoco samples select wells for constituents of concern (COCs) established in the CCR in AOI 8 on an annual basis. Quarterly, semi-annual and annual gauging and sampling activities, as well as the routine operation and maintenance data for the AOI 8 remedial systems, are reported to the PADEP and US EPA in Quarterly Reports.

### 1.1 Objectives

The objective of the proposed activities in this work plan is to characterize current environmental conditions at AOI 8 in accordance with the 2003 Consent Order and Agreement (CO&A) between Sunoco and the PADEP and the 2004 CCR. This work plan also includes activities to address any remaining issues pertaining to the characterization of the Resource, Conservation and Recovery Act (RCRA) Solid Waste Management Unit (SWMU) in AOI 8 known as SWMU 2 – Former Leaded Tank Bottoms Sludge Weathering Pad. This SWMU is discussed in detail in Section 1.2.1 of this work plan. The LTU was closed under a Consent Order and Agreement (CO&A) between PADEP and Sunoco and is currently undergoing post-closure monitoring activities. Therefore, no characterization work is proposed in the LTU.

Below is a list of the general site characterization activities proposed at AOI 8 and discussed in this work plan:

- Review of all available historical environmental reports relating to AOI 8;
- Evaluate performance of existing remediation systems;
- Advance shallow soil borings and collect shallow soil samples for laboratory analysis of Site compounds of concern (COCs);
- Install shallow groundwater monitoring wells;
- Survey all new wells and soil boring locations;
- Collect groundwater samples for laboratory analysis of Site COCs from all new and existing shallow and deep groundwater monitoring wells;
- Collect samples for characterization of light non-aqueous phase liquid (LNAPL) from select newly-installed monitoring wells;
- Complete LNAPL modeling to evaluate LNAPL specific volume and mobility;

- Evaluate potential vapor migration pathways using the PADEP's vapor intrusion guidance;
- Complete fate and transport modeling of dissolved COCs in site groundwater;
- Complete exposure and risk assessment activities, if necessary; and
- Prepare a Site Characterization Report detailing the results of the characterization activities.

The COCs for the proposed investigation activities include all constituents listed in Tables 5a and 5b of the CCR, and are included as Table 1 of this work plan. Data collected from the above activities will be evaluated as part of the AOI 8 site characterization process. This data will be presented in the Site Characterization Report for AOI 8 which is anticipated to be submitted to PADEP and US EPA by September 30, 2008 in accordance with the revised Phase II Corrective Action Schedule (Appendix A).

### 1.2 Overview of Investigative Framework and Remedial Approach for AOI 8

The current remediation program for the Refinery is performed under the 2003 CO&A between PADEP and Sunoco. In April 2004, the PADEP and US EPA signed an agreement entitled "One Cleanup Program Memorandum of Agreement (MOA or One-Cleanup Program)," which clarifies how sites remediated under Pennsylvania's Act 2 program may satisfy RCRA corrective action requirements through characterization and attainment of Act 2 remediation standards pursuant to Pennsylvania's Act 2. On November 22, 2005, Sunoco and its representatives met with officials of the PADEP and US EPA to discuss the applicability of the Sunoco Philadelphia Refinery to the One Cleanup Program. During the November 22, 2005 meeting, all parties agreed that the One Cleanup Program would benefit the project by merging the remediation obligations under the various programs into one streamlined approach which would be conducted under the existing 2003 CO&A. As a follow up to the meeting, Sunoco submitted a letter dated December 2, 2005 to US EPA and PADEP documenting the discussions at the meeting (Appendix B). As summarized in this letter, the major aspects of including the Philadelphia Refinery in the One-Cleanup Program include:

1. Submittal of a Notice of Intent to Remediate (NIR) under the PADEP Act 2 Program. Sunoco submitted a NIR for the Refinery, excluding the Belmont Terminal, to the PADEP on October 12, 2006. The NIR was accompanied by a cover letter which requested that the Refinery be included in the PA One-

Cleanup Program and that all remediation work will be completed under the 2003 CO&A. RCRA corrective action measures will be addressed concurrently with work performed under the CO&A and within the Act 2 program. The City of Philadelphia requested that a Public Involvement Plan be prepared in response to the NIR. Sunoco held a public involvement meeting in South Philadelphia on September 19, 2007.

2. Sunoco is currently in the process of revising the corrective action permit for the Philadelphia Refinery to embody the Pennsylvania One Cleanup Plan elements.

An overview of the RCRA corrective action program for the Point Breeze North Yard (AOI 8) portion of the Philadelphia Refinery is provided in the following section.

#### *1.2.1 Overview of RCRA Corrective Action Program in AOI 8*

A number of RCRA investigations were completed in AOI 8 between 1986 and 1988 on behalf of Atlantic Refining and Marketing (Atlantic), the subsidiary of Sunoco, Inc. that owns the Point Breeze portion of the Philadelphia Refinery. Atlantic has leased the Point Breeze portion of the Philadelphia Refinery to Sunoco, Inc. (R&M), a subsidiary that operates the Philadelphia Refinery. These investigations included a Phase I Preliminary Review of SWMU's, a RCRA Facility Assessment, and a RCRA Verification Work Plan. On December 9, 1988, US EPA issued a Corrective Action and Waste Minimization Permit for the Point Breeze portion of the Refinery that identified six SWMUs. This permit required additional investigation of the SWMUs to determine if corrective action was needed. One of the SWMUs (SWMU 2 – Leaded Tank Bottoms Sludge Weathering Pad) is located in AOI 8; the remaining SWMUs are located in other AOIs at the Refinery. In 1991, a RCRA Facility Investigation (RFI) Work Plan was prepared by CH2MHill for the Refinery. The RFI Work Plan described SWMU 2 as a 50-foot by 100-foot area on which leaded gasoline storage tank bottoms sludge was placed and allowed to weather. SWMU 2 is shown in Figure 2. The startup date of the SWMU was not known, however, according to previous reports (A.T. Kearney, Inc, 1986 and NUS Corporation, 1988), the unit was reportedly constructed of naturally occurring soil and fill material and was closed in the mid-1960s. According to GES (GES, 1989), the area served as a leaded sludge weathering pad during two distinct time periods. Prior to 1959, leaded sludges were deposited in a pit at the location of the weathering pad. A

Refinery building occupied this area from 1959 to 1975. In 1975, the building was razed and the remaining concrete slab foundation was used to weather leaded tank bottoms sludge. The sludge weathering area was closed again in 1980 by transferring weathered sludges to a new sludge weathering unit. The concrete pad was reportedly swept clean of residual materials and covered with clean gravel (GES, 1989). The RFI Work Plan recommended that a geophysical survey be completed in the area to determine the orientation and location of the former sludge weathering pad. The RFI Work Plan also recommended that soil samples be collected from four test trenches to be excavated around the perimeter of the pad after the pad boundary is delineated by the geophysical survey.

The results of the RCRA Facility Investigation were presented in a report prepared by ENSR Consulting and Engineering dated September 1992 (RFI). The RFI was conducted in accordance with CH2MHill's 1991 RFI Work Plan. As part of the RFI, a geophysical survey was completed to delineate the extent of the concrete pad. The RFI documented that the dimensions of the former sludge weathering pad (SWMU 2) in AOI 8 was 50 by 400 feet, not 50 by 100 feet as described in the RFI Work Plan. Nine test trenches were then excavated around the perimeter of the pad on March 4 and 5, 1992. A total of 17 soil samples were collected from the trenches and submitted for laboratory analysis and the results are described in the RFI. No soil samples were collected from soil between zero and two feet beneath the ground surface around the perimeter of the pad. Concentrations of lead in two of the 17 soil samples collected at depths greater than two feet exceeded the current PADEP Medium Specific Concentration (MSC) of 450 mg/kg; all other samples exhibited lead concentrations below 450 mg/kg.

This Work Plan includes a plan to characterize soil at this SWMU in accordance with the objectives of the 2003 CO&A, the CCR and the PA One Cleanup Program. SWMU 2 is identified as the only SWMU in AOI 8 requiring further investigation. The approach to investigating SWMU 2 is described in detail in Section 1.2.2. If site characterization and or remediation are completed at SWMU 2 in accordance with the approach discussed herein, the RCRA obligations for this area in AOI 8 will be satisfied if the PADEP and US EPA have approved of the work completed as documented in the Site Characterization Report.

### 1.2.2 Overview of Proposed Approach for SWMU 2

The proposed approach to address soils within SWMU 2 will support a RCRA final remedial measure, as well as support attainment of an Act 2 remediation standard, consistent with the One Cleanup Plan. The proposed approach is consistent with the approach used for other AOIs which have been previously characterized and contain leaded tank bottom SWMUs (i.e., AOI 5 and AOI 6).

Leaded Tank Bottom materials are distinguished by distinctive rust/red to black, metallic mostly oxidized scale materials. Leaded Tank Bottoms are also sometimes in a matrix of petroleum wax sludge. If materials are encountered in soil within the leaded tank bottom areas matching the physical description of the leaded tank bottoms, then Sunoco will collect samples for total lead. If the total lead results exceed 450 parts per million (ppm) (PADEP's non-residential soil MSC for lead), then the samples will be analyzed for lead via Toxicity Characteristic Leaching Procedure, EPA Test Method 1311. Delineated areas that have soils that physically resemble leaded tank bottoms, have concentrations of total lead exceeding 450 ppm, and are hazardous for lead, will retain the leaded tank bottom designation. If no soils are encountered that meet all three of these criteria, then the area will no longer be classified as a leaded tank bottom area. Sunoco will certify that these areas will no longer contain leaded tank bottoms materials, based on the procedures above, in the Site Characterization Report. The proposed soil sampling program for this portion of SWMU 2 is presented in detail in Section 2.1.

### 1.2.3 Overview of Proposed Approach in Non-RCRA Areas of AOI 8

The proposed approach to address groundwater and soils in the remainder of AOI 8 is in accordance with the Act 2 program. Sampling will be focused to further characterize the volume and mobility of LNAPL and the extent of site COCs in soil and groundwater. Additional soil borings or well installations may also be completed throughout AOI 8 to ensure that site soils and groundwater are fully characterized in accordance with the Act 2 program.

### *1.2.4 Overview of the Land Farm Treatment Unit (LTU) in AOI 8*

The LTU is located in the northwestern portion of AOI 8 and encompasses approximately 20 acres. The LTU was closed under a Consent Order and Agreement (CO&A) between PADEP and Sunoco and is currently undergoing post-closure monitoring activities. Therefore, no characterization work is proposed in the LTU. A narrative describing the history and current status of the LTU will be provided in the Site Characterization Report to be prepared for AOI 8 following implementation of this work plan.

## 1.3 Overview of Existing Phase I Activities in AOI 8

Currently four active remediation systems operate in the North Yard. These systems are: the PGW Border Total Fluids Recovery System, the Jackson Street Sewer Total Fluids Recovery System, the North Yard Bulkhead / No. 3 Tank Farm Separator Total Fluids Recovery System, and the Jackson Street Sewer Water Curtain. These remediation systems are discussed below. Remediation system performance and monitoring data is summarized in quarterly reports that are provided to the PADEP and US EPA.

The PGW Border Total Fluids Recovery System is composed of recovery wells numbered RW-200 through RW-205 and an interceptor trench with a recovery sump (RW-206). The system was installed to address offsite migration of LNAPL. The system recovery network consists of total fluids recovery utilizing electric submersible pumps equipped with individual timers to control the on and off cycle of each pump. Total fluids are extracted from wells RW-201, RW-202, and RW-203. Total fluids produced by the 200 series pumps are routed to the North Yard 10,000-gallon holding tank where a flow meter measures incoming fluids produced by the three recovery wells. Groundwater is passed through the tank and routed to the Point Breeze Processing Area Wastewater Treatment Plant. Accumulated LNAPL is pumped out of the 10,000-gallon holding tank as needed by a vacuum truck.

The Jackson Street Sewer Total Fluids Recovery System network consists of total fluids (groundwater and LNAPL) recovery utilizing electric submersible pumps equipped with individual timers to control the pumping at each recovery well. The system was installed to address LNAPL migration to the Jackson Street Sewer and the Schuylkill River. The recovery network includes a total of three wells, RW-300, RW-301, and RW-302. Total fluids produced from the wells are routed to the North Yard 10,000-gallon holding tank where a flow meter records the combined total fluids produced from the Jackson Street recovery well network. Recovered water is passed through the tank and routed to the Point Breeze Processing Area Wastewater Treatment Plant. Accumulated LNAPL is pumped out of the 10,000-gallon holding tank as needed by a vacuum truck.

The North Yard Bulkhead Total Fluids Recovery System consists of a 3,400-foot long interceptor trench with two recovery sumps (RW-500 and RW-501). The No. 3 Tank Farm Separator Total Fluids Recovery System consists of one recovery system RW-502 located in the center of the capped closed separator. This system was installed to address LNAPL migration to the Schuylkill River. RW-500, RW-501 and RW-502 utilize electric submersible pumps controlled by a timer to recover total fluids. The total fluids from the three recovery wells are pumped to the North Yard 10,000-gallon holding tank where a flow meter measures incoming fluids produced by the recovery wells. Groundwater is passed through the tank and routed to the Point Breeze Processing Area Wastewater Treatment Plant. Accumulated LNAPL is pumped out of the 10,000-gallon holding tank as needed by a vacuum truck.

In addition to the four remediation systems, a water curtain in Jackson Street Sewer was installed during 4th quarter 2003. The water curtain is designed to reduce hydrocarbon odors potentially migrating from Jackson Street sewer to the surrounding areas. The water curtain apparatus is located in the first manhole west of the interceptor chamber along 26$^{th}$ Street and consists of a single centrally located nozzle that emits a radial spray pattern. Recovered water is supplied to the water curtain apparatus from the North Yard fire water system. Heat trace was run along the water feed line allowing winter operation of the water curtain.

No additional Phase I corrective action activities are proposed in this work plan. The effectiveness of the existing AOI 8 remedial systems and the need to perform additional active remediation in AOI 8 will be evaluated following completion of the proposed site characterization activities.

### 1.4 Work Plan Support Activities

Several activities were performed to support the development of this work plan. These activities are summarized on the following page:

- Aquaterra Technologies, Inc. (Aquaterra) performed a round of groundwater monitoring and sampling in AOI 8 between February 4 and 8, 2008. All accessible wells in AOI 8 were gauged and select wells (40 total) were sampled for site COCs. The wells for sampling were selected to obtain a spatial representation of groundwater quality throughout AOI 8. The groundwater samples were submitted to Lancaster Laboratories of Lancaster, Pennsylvania (Act 2-certified) for analysis of site COCs. The results of these samples are presented in Tables 2a and 2b of this work plan. This data was obtained to enhance the Site Conceptual Model for AOI 8 and to refine site characterization activities proposed in this work plan;

- Aquaterra collected LNAPL from select wells which contained measurable (<0.01) LNAPL and submitted the samples to Torkelson Geochemistry, of Tulsa, Oklahoma for LNAPL characterization. This data was obtained to enhance the Site Conceptual Model for AOI 8 and to refine site characterization activities proposed in this work plan;

- Available historical aerial photographs with coverage of AOI 8 were obtained and reviewed to identify specific areas for characterization and to assist in determining previous industrial uses of AOI 8. Aerial photos were reviewed for the following years: 1928, 1930, 1943, 1959, 1965, 1970, 1973, 1975, 1980, 1985, 1986, 1990, 1992, 1995; and

- Historic reports and reports used in development of the CCR were reviewed to evaluate and refine site characterization activities proposed in this work plan. Key reports included:

    - *The Atlantic Lead Weathering Pad Final Closure Report, Sun Refining and Marketing Company, Atlantic Refining and Marketing Corporation, Philadelphia Refinery*, prepared by K.W. Brown & Associates, Inc., dated March 1991;

    - *RCRA Facility Investigation Work Plan, Philadelphia Refinery, Sun Refining and Marketing Company, Philadelphia Pennsylvania*, prepared by CH2MHILL, dated May 1991;

    - *Comprehensive Remedial Plan, Philadelphia Refinery, Sun Company (R&M),* prepared by ENSR Consulting and Engineering, dated September 1993;

- *Remedial Action Plan for the No. 3 Tank Farm Separator, Sun Company (R&M), Philadelphia Refinery*, prepared by ENSR Consulting and Engineering, dated October 1993;

- *Remedial Action Plan for the North Yard Bulkhead, Sun Company (R&M), Philadelphia Refinery*, prepared by ENSR Consulting and Engineering, dated October 1993;

- *Remedial Action Plan for the North Yard Southern Property Boundary, Sun Company (R&M), Philadelphia Refinery*, prepared by ENSR Consulting and Engineering, dated December 1993;

- *Consent Order and Agreement by and between the Commonwealth of Pennsylvania, Department of Environmental Protection, Atlantic Refining & Marketing Corporation and Sunoco Company, Inc. (R&M), dated August 1996, and amended December 2000 and July 2004;*

- *Corrective Measures Study Work Plan, Sun Company, Inc. (R&M), Philadelphia, Pennsylvania,* prepared by ENSR Consulting and Engineering, dated April 1997;

- *Landfarm Treatment Unit Closure Activation Report, Philadelphia Refinery Point Breeze Processing Area*, prepared by Blazosky Associates, Inc., dated November 2000;

- *Amended Closure Plan, Sunoco, Inc. Philadelphia Refinery, Point Breeze Processing Area, Land Treatment Unit,* prepared by Blazosky Associates, Inc., originally dated November 1988 and amended November 2002 and May 2004; and

- *Amended Post-Closure Plan, Sunoco, Inc. Philadelphia Refinery, Point Breeze Processing Area, Land Treatment Unit,* prepared by Blazosky Associates, Inc., originally dated November 1988 and amended June 2003 and May 2004.

## 2.0 PROPOSED SITE CHARACTERIZATION ACTIVITIES

Based on the identified data collection needs for AOI 8, the following site characterization tasks are proposed and included in this work plan:

**Task 1:** **Shallow Soil Borings and Sampling**
**Task 2** **Installation of Shallow/Intermediate Groundwater Monitoring Wells and Deep Soil Borings**
**Task 3:** **Groundwater Monitoring and Sampling**
**Task 4:** **Collection and Characterization of LNAPL Samples**
**Task 5:** **Review of Available Aquifer Test Data**
**Task 6:** **Evaluation of the Potential Vapor Intrusion into Indoor Air Pathway**
**Task 7:** **Fate and Transport Analysis of Dissolved COCs in Groundwater**
**Task 8:** **Exposure and Risk Assessment**
**Task 9:** **Surveying**
**Task 10:** **Data Evaluation and Site Conceptual Model**
**Task 11:** **Reporting**

The individual site characterization tasks included in this work plan are discussed in detail in the following sections.

### 2.1 Shallow Soil Borings and Soil Sampling

To further characterize shallow soil conditions within AOI 8, a total of 37 shallow soil borings will be completed. The locations of the borings are shown on Figure 2. Twenty-four of the 37 soil boring locations were selected to characterize shallow soil at areas with possible historic environmental concerns, including former process and tank areas, and other areas identified from reviewing historic reports and aerial photographs. The remaining soil boring locations were selected in a random manner to spatially represent other areas of AOI 8. Each shallow soil boring will be advanced from zero to two feet beneath the ground surface and one soil sample will be collected from each boring for laboratory analysis of site COCs. One shallow soil sample will also be collected from zero to two feet beneath the ground surface at each proposed groundwater monitoring well location (see Section 2.2). Soil samples will only be collected from those areas that are not covered by impervious surfaces. Soil boring and sample collection procedures are outlined in Section C.3 of Appendix C and the proposed soil boring locations are shown on Figure 2. A summary of the proposed soil sampling activities is included in Table 3.

SWMU 2 - Former Leaded Tank Bottoms Sludge Weathering Pad

Four soil borings will be advanced around the perimeter of the existing concrete pad and two soil samples will be advanced through the northern portion of the existing concrete pad (at the location of the former sludge pit beneath the pad) at SWMU 2 in accordance with Section 1.2.2 of this work plan. These soil borings will be advanced to a depth of six feet beneath the ground surface using a hand-auger or geoprobe. Soil samples will be collected from SWMU 2 in accordance with the procedures described in section C.3 of Appendix C. If necessary, soil samples will be submitted to Lancaster Laboratories for analysis of total lead, and for TCLP lead analysis in accordance with Section 1.2.2.

## 2.2 Task 2: Installation of Shallow/Intermediate Groundwater Monitoring Wells

Thirty-nine fill and alluvium (shallow) or Trenton gravel (intermediate) groundwater monitoring wells are proposed to be installed in AOI 8 as shown on Figure 2 and summarized on Table 3. At four well locations, the well borings will be advanced to the top of bedrock for characterization of geology. The well borings will be advanced using hollow stem auger drilling methods and screened within the shallow or intermediate zone. All wells will be installed so that the screened interval intercepts the groundwater table, allowing for appropriate measurement of apparent LNAPL thickness. Each well will be developed subsequent to completion. All well installation, well development, and waste handling activities will be performed in accordance with the procedures described in Appendix C of this work plan.

Fourteen deep (Lower Sand) groundwater monitoring wells exist in AOI 8. These wells include N-13, N-19, N-21, N-27, N-30, N-38D, N-4, N-43, N-46D, N-50D, N-69, N-79, N-83, and N-9. As part of AOI 8 characterization, the classification of these wells will be re-evaluated considering geology and well construction. Any changes to the classifications of these wells will be described in the Site Characterization Report for AOI 8. No additional deep groundwater monitoring wells are proposed to be installed in AOI 8 as part of this work plan.

## 2.3 Task 3: Groundwater Monitoring and Sampling

### *2.3.1 Groundwater Monitoring*

Upon completion of the monitoring well installations and development in AOI 8, a complete round of groundwater water elevation gauging will be performed from all accessible new and existing monitoring wells in AOI 8. All well gauging activities will be performed in accordance with the Liquid Level Gauging Procedures described in Appendix C of this work plan. Monitoring well gauging data collected during this event will be used to evaluate groundwater flow conditions and the occurrence and extent of apparent LNAPL in AOI 8.

### *2.3.2 Groundwater Sampling*

Following completion of the groundwater gauging activities in the AOI 8, a full round of groundwater sampling will be conducted from all accessible new and existing monitoring wells that do not contain measurable LNAPL. All groundwater samples will be submitted to Lancaster Laboratories for analysis of site COCs, as listed in Table 1. Groundwater sampling will be conducted in accordance with well sampling procedures described in Appendix C of this Work Plan. Groundwater samples will not be collected from wells containing LNAPL and may not be collected from active recovery wells.

## 2.4 Task 4: Collection and Characterization of LNAPL Samples

LNAPL characterization data exists for 22 wells in AOI 8. LNAPL from 11 wells (N-14, N-25, N-31, N-35, N-48, N-52, N-68, N-78, N-79, PZ-204 and PZ-502) was characterized in support of the CCR and LNAPL from 11 wells (N-42, N-47, N-51, N-75, N-76, N-82, N-91, N-503, RW-205, RW-300 and RW-305) was collected by Aquaterra and characterized in support of this Work Plan.

As part of implementation of this Work Plan, additional LNAPL samples will be collected from existing or newly installed monitoring wells that have measurable LNAPL thicknesses and are not located in the immediate vicinity of a well with known LNAPL type. All LNAPL sampling activities will be completed in accordance with the section C.4 in Appendix C of this Work Plan. The LNAPL samples will be submitted to Torkelson Geochemistry of Tulsa, Oklahoma for characterization. The results of the LNAPL characterization analysis will be used to separate LNAPL plumes by product type and to assist in evaluating specific LNAPL volume and mobility. All LNAPL data for AOI 8 will be summarized in the Site Characterization Report.

### 2.5 Task 5: Review of Available Aquifer Test Data

Langan reviewed relevant historical documents prepared for AOI 8 to determine if specific aquifer data that may have been collected during previous environmental investigations was available. Based on the review, sufficient aquifer data exists, including data from numerous bail-down tests, slug tests, and step and constant rate pumping tests completed in AOI 8 by others. These data will be further evaluated and summarized as a part of the Site Characterization Report. Based on the sufficiency of this data, no further aquifer testing is proposed to be completed in AOI 8 as part of this Work Plan.

### 2.6 Task 6: Evaluation of the Potential Vapor Intrusion (VI) into Indoor Air Pathway

As presented in the CCR, there are three potential indoor air receptors in AOI 8. The boiler house building is located in the center of AOI 8 and is operated by Sunoco. As such, this building is covered under the Refinery's OSHA monitoring plan. The other two buildings are located in the southwest portion of AOI 8 and are currently used by the U.S. Coast Guard. These buildings are not covered under the Refinery's OSHA monitoring plan.

Sunoco will be sampling indoor air within the boiler house to evaluate the potential VI pathway. The results of the sampling will be compared to the OSHA permissible exposure limits. The results of this sampling will determine whether further investigation will be performed to assess the potential VI pathway at this building. The potential VI pathway at the two Coast Guard buildings will be evaluated in accordance with the PADEP's VI guidance. The results of the VI evaluations for all receptors will be summarized in the Site Characterization Report.

## 2.7 Task 7: Fate and Transport Analysis of Dissolved COCs in Groundwater

Fate and transport calculations will be completed for groundwater to evaluate potential migration pathways and potential impacts to receptors, as necessary. Fate and transport modeling will be conducted for the constituents listed in Table 1 using PADEP approved analytical models (QUICK_DOMENICO.XLS and FATBACK.XLS and PENTOXSD). To support the fate and transport analyses, Sunoco will provide all assumptions, data and information used in the analytical modeling. The parameters used in the analyses will either be site-specific data obtained during previous investigations, values collected as part of future site characterization activities, and/or default parameters provided in the Act 2 regulations or guidance manual.

## 2.8 Task 8: Exposure and Risk Assessment

In accordance with Title 25, Chapter 250, Subchapter F, a detailed exposure assessment will be performed for AOI 8 based on the completed site characterization activities. This exposure assessment will be based on an assumed non-residential current and future site use. If completed exposure pathways are identified, then risk assessment activities will be completed in accordance with Act 2.

## 2.9 Task 9: Surveying

Sunoco surveyed all existing wells in AOI 8 in November 2007 in support of this work plan. Following completion of proposed soil boring and groundwater monitoring well installation activities, the new boring and well locations will be surveyed to establish the location and elevation at each boring, and the elevations of the inner and outer casing and ground surface (for wells). The well elevations will be determined to the nearest 0.01 foot relative to mean sea level. All survey activities will be performed by a Pennsylvania-licensed surveyor and referenced to the NAVD 88 datum.

## 2.10 Task 10: Data Evaluation and Site Conceptual Model

Data collected from the site characterization activities will be compiled and evaluated in accordance with the objectives of the 2003 CO&A and the CCR. This data will also be used to modify and refine the Site Conceptual Model. Site characterization activities described in this work plan will provide the following information to be used in refining the Site Conceptual Model:

- Soil data collected between zero and two feet below the ground surface from select soil borings will further characterize the potential direct contact exposure pathway for soil;

- Soil data collected from within SWMU 2 will further characterize conditions in accordance with Section 1.2.2;

- Installation, monitoring and sampling of new groundwater monitoring wells will further characterize groundwater quality and flow in AOI 8;

- New and existing LNAPL data in AOI 8 will allow for more accurate LNAPL classification and distribution estimates, and will refine the LNAPL specific volume and mobility modeling predictions for these areas. This data may support the optimization of existing remedial systems in AOI 8 or the design of new remedial systems in AOI 8, if necessary;

- Fate and transport modeling of dissolved phase COCs in groundwater will further characterize the potential for migration of dissolved phase COCs in groundwater in AOI 8;

- Updated survey data will allow for accurate depiction and evaluation of data points; and

- Throughout the characterization process of AOI 8, additional information regarding the current and historic uses of these areas will be obtained from available sources. Information obtained will be used to generate more detailed Current and Historic Usage figures that may be included in the Site Characterization Report, if necessary.

Data collected during this characterization process will be used to augment the existing geographic information system (GIS) database for the Refinery. The GIS will be used to further evaluate characterization needs and to visually depict current and future site conditions.

### 2.11 Task 11: Reporting

Following completion of the activities listed above in Tasks 1 through 10, a Site Characterization Report will be prepared for AOI 8 documenting the results of all work plan-related activities. Copies of the report will be submitted to the PADEP and US EPA for review and approval. The report will include an executive summary, description of physical site characteristics, summary of field investigation and modeling activities, supporting maps, figures and data summary tables, an exposure assessment, refinement of the Site Conceptual Model based on field investigations, and conclusions and recommendations for future site characterization and/or remedial activities, if any.

All data gathered with respect to the deep aquifer, AOI 11, will be presented in the respective AOI reports; however, a formal characterization report for AOI 11 will be compiled at the conclusion of all other AOI characterization efforts.

## 3.0 IMPLEMENTATION SCHEDULE

Site characterization activities described in this work plan are anticipated to begin in May 2008. It is anticipated that all field activities will be completed by June 2008. The Site Characterization Report for AOI 8 will be submitted to the PADEP and US EPA by September 30, 2008. This schedule is consistent with the revised Phase II Corrective Action Activities Schedule, which is included as Appendix A.

During the Work Plan implementation, if any significant deviations are required from the proposed scope of work, the PADEP and US EPA will be notified prior to implementation of any changes to the work scope.

## 4.0 REFERENCES

RCRA Facility Investigation Work Plan, Philadelphia Refinery, Sun Refining and Marketing Company, Philadelphia Pennsylvania, CHM2HILL, May 1991;

The Atlantic Lead Weathering Pad Final Closure Report, Sun Refining and marketing Company, Atlantic Refining and marketing Corporation, Philadelphia Refinery, K.W. Brown & Associates, Inc., March 1991;

Comprehensive Remedial Plan, Philadelphia Refinery, Sun Company (R&M), September 1993, ENSR Consulting and Engineering;

Remedial Action Plan for the NO.3 Tank Farm Separator, Sun Company (R&M), Philadelphia Refinery, October 1993, ENSR Consulting and Engineering;

Remedial Action Plan for the North Yard Bulkhead, Sun Company (R&M), Philadelphia Refinery, October 1993, ENSR Consulting and Engineering;

Remedial Action Plan for the North Yard Southern Property Boundary, Sun Company (R&M), Philadelphia Refinery, December 1993, ENSR Consulting and Engineering;

Consent Order and Agreement by and between the Commonwealth of Pennsylvania, Department of Environmental Protection, Atlantic Refining & Marketing Corporation and Sunoco Company, Inc. (R&M), August 1996, and amended December 2000 and July 2004;

Corrective Measures Study Work Plan, Sun Company, Inc. (R&M), Philadelphia, PA, April 1997, ENSR Consulting and Engineering;

Landfarm Treatment Unit Closure Activation Report, Philadelphia Refinery Point Breeze Processing Area, November 2000, Blazosky Associates, Inc.;

Amended Closure Plan, Sunoco, Inc. Philadelphia Refinery, Point Breeze Processing Area, Land Treatment Unit, November 1988 and amended November 2002 and May 2004, Blazosky Associates, Inc; and

Amended Post-Closure Plan, Sunoco, Inc. Philadelphia Refinery, Point Breeze Processing Area, Land Treatment Unit, November 1988 and amended June 2003 and May 2004, Blazosky Associates, Inc.

# TABLES

**Table 1**
**Constituents of Concern for Groundwater**
**AOI 8 Work Plan for Site Characterization**
**Sunoco Philadelphia Refinery**
**Philadelphia, Pennsylvania**

| METALS | CAS No. |
|---|---|
| Lead (dissolved) | 7439-92-1 |

| VOLATILE ORGANIC COMPOUNDS | CAS No. |
|---|---|
| 1,2-dichloroethane | 107-06-2 |
| Benzene | 71-43-2 |
| Cumene | 98-82-8 |
| Ethylbenzene | 100-41-4 |
| Ethylene dibromide | 106-93-4 |
| Methyl tertiary butyl ether | 1634-04-4 |
| Toluene | 108-88-3 |
| Xylenes (total) | 1330-20-7 |

| SEMI-VOLATILE ORGANIC COMPOUNDS | CAS No. |
|---|---|
| Chrysene | 218-01-9 |
| Fluorene | 86-73-7 |
| Naphthalene | 91-20-3 |
| Phenanthrene | 85-01-8 |
| Pyrene | 129-00-0 |

Notes:
1. Constituents are from Pennsylvania Corrective Action Process (CAP) Regulation Amendments effective December 1, 2001; provided in Chapter VI, Section E (pgs. 29-30) of PADEP Document, *Closure Requirements for Underground Storage Tank Systems,* effective April 1, 1998.

**Table 1 (continued)**
**Constituents of Concern for Soil**
**AOI 8 Work Plan for Site Characterization**
**Sunoco Philadelphia Refinery**
**Philadelphia, Pennsylvania**

| METALS | CAS No. |
|---|---|
| Lead (total) | 7439-92-1 |

| VOLATILE ORGANIC COMPOUNDS | CAS No. |
|---|---|
| 1,2-dichloroethane | 107-06-2 |
| Benzene | 71-43-2 |
| Cumene | 98-82-8 |
| Ethylbenzene | 100-41-4 |
| Ethylene dibromide | 106-93-4 |
| Methyl tertiary butyl ether | 1634-04-4 |
| Toluene | 108-88-3 |
| Xylenes (total) | 1330-20-7 |

| SEMI-VOLATILE ORGANIC COMPOUNDS | CAS No. |
|---|---|
| Anthracene | 120-12-7 |
| Benzo(a)anthracene | 56-55-3 |
| Benzo (g,h,i) perylene | 191-24-2 |
| Benzo(a)pyrene | 50-32-8 |
| Benzo(b)fluoranthene | 205-99-2 |
| Chrysene | 218-01-9 |
| Fluorene | 86-73-7 |
| Naphthalene | 91-20-3 |
| Phenanthrene | 85-01-8 |
| Pyrene | 129-00-0 |

Notes:
1. Constituents are from Pennsylvania Corrective Action Process (CAP) Regulation Amendments effective December 1, 2001; provided in Chapter VI, Section E (pgs. 29-30) of PADEP Document, *Closure Requirements for Underground Storage Tank Systems,* effective April 1, 1998.

# Table 2a
## Summary of
## Fill / Alluvium Groundwater Analytical Results
## AOI 8 Workplan
## Sunoco Philadelphia Refinery
## Philadelphia, Pennsylvania
## February 2008

| | CAS No | PADEP Non-Residential Used Aquifer MSC for Groundwater TDS<2,500 | Sample ID<br>Sample Date<br>Sample Matrix | Field Blank<br>2/8/2008<br>Groundwater | | | N-1<br>2/6/2008<br>Groundwater | | | N-10<br>2/6/2008<br>Groundwater | | | N-11<br>2/6/2008<br>Groundwater | | | N-12<br>2/7/2008<br>Groundwater | | | N-16<br>2/6/2008<br>Groundwater | | | N-17<br>2/6/2008<br>Groundwater | | | N-18<br>2/6/2008<br>Groundwater | | | N-20<br>2/7/2008<br>Groundwater | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Volatile Organic Compounds** | | | **Unit** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** |
| Ethylbenzene | 100-41-4 | 700 | ug/l | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | 1.00 | | 1.00 | 1.00 | | 1.00 | ND | U | 1.00 | ND | U | 1.00 | 2.00 | | 1.00 | 1.00 | U | 1.00 |
| Ethylene dibromide (EDB) | 106-93-4 | 0.05 | ug/l | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 | 0.03 | U | 0.03 | 0.03 | | 0.03 | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 | 0.03 | U | 0.03 |
| 1,2-Dichloroethane | 107-06-2 | 5 | ug/l | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | 1.00 | U | 1.00 | 1.00 | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | 1.00 | U | 1.00 |
| Toluene | 108-88-3 | 1000 | ug/l | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | 11.00 | | 1.00 | 9.00 | | 1.00 | ND | U | 1.00 | ND | U | 1.00 | 3.00 | | 1.00 | 1.00 | U | 1.00 |
| Xylene (Total) | 1330-20-7 | 10000 | ug/l | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | 15.00 | | 1.00 | 12.00 | | 1.00 | ND | U | 1.00 | ND | U | 1.00 | 2.00 | | 1.00 | 1.00 | U | 1.00 |
| Methyl Tertiary Butyl Ether | 1634-04-4 | 20 | ug/l | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | 1.00 | J | 1.00 | 1.00 | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | 1.00 | U | 1.00 |
| Benzene | 71-43-2 | 5 | ug/l | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | 10.00 | | 1.00 | 6.00 | | 1.00 | ND | U | 1.00 | ND | U | 1.00 | 5.00 | | 1.00 | 1.00 | U | 1.00 |
| Cumene | 98-82-8 | 2300 | ug/l | ND | U | 2.00 | ND | U | 2.00 | 12.00 | | 2.00 | 45.00 | | 2.00 | 14.00 | | 2.00 | ND | U | 2.00 | ND | U | 2.00 | 75.00 | | 2.00 | 42.00 | | 2.00 |
| **Semi-Volatile Organic Compounds** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Pyrene | 129-00-0 | 130 | ug/l | ND | U | 5.00 | ND | U | 5.00 | 13.00 | | 5.00 | 3.00 | J | 5.00 | 160.00 | | 50.00 | ND | U | 5.00 | 15.00 | | 5.00 | 9.00 | | 5.00 | 73.00 | | 50.00 |
| Chrysene | 218-01-9 | 1.9 | ug/l | ND | U | 5.00 | ND | U | 5.00 | 8.00 | | 5.00 | 1.00 | J | 5.00 | 74.00 | | 50.00 | ND | U | 5.00 | 2.00 | J | 5.00 | 6.00 | | 5.00 | 54.00 | | 50.00 |
| Phenanthrene | 85-01-8 | 1100 | ug/l | ND | U | 5.00 | ND | U | 5.00 | 6.00 | | 5.00 | 12.00 | | 5.00 | 690.00 | | 50.00 | ND | U | 5.00 | ND | U | 5.00 | 15.00 | | 5.00 | 50.00 | U | 50.00 |
| Fluorene | 86-73-7 | 1900 | ug/l | ND | U | 5.00 | ND | U | 5.00 | ND | U | 5.00 | 8.00 | | 5.00 | 190.00 | | 50.00 | ND | U | 5.00 | ND | U | 5.00 | 10.00 | | 5.00 | 62.00 | | 50.00 |
| Naphthalene | 91-20-3 | 100 | ug/l | ND | U | 5.00 | ND | U | 5.00 | ND | U | 5.00 | 5.00 | U | 5.00 | 50.00 | U | 50.00 | ND | U | 5.00 | ND | U | 5.00 | ND | U | 5.00 | 50.00 | U | 50.00 |
| **Metals** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Lead (Total) | 7439-92-1 | 5 | mg/l | ND | U | 0.00100 | ND | U | 0.00100 | 0.00071 | | 0.00100 | 0.00100 | U | 0.00100 | 0.00100 | U | 0.00100 | ND | U | 0.00100 | ND | U | 0.00100 | 0.00011 | J | 0.00100 | 0.03820 | | 0.00100 |

| | CAS No | PADEP Non-Residential Used Aquifer MSC for Groundwater TDS<2,500 | Sample ID<br>Sample Date<br>Sample Matrix | N-28<br>2/6/2008<br>Groundwater | | | N-29<br>2/7/2008<br>Groundwater | | | N-3<br>2/7/2008<br>Groundwater | | | N-32<br>2/7/2008<br>Groundwater | | | N-36<br>2/7/2008<br>Groundwater | | | N-37<br>2/7/2008<br>Groundwater | | | N-38<br>2/7/2008<br>Groundwater | | | N-40<br>2/8/2008<br>Groundwater | | | N-41<br>2/8/2008<br>Groundwater | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Volatile Organic Compounds** | | | **Unit** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** |
| Ethylbenzene | 100-41-4 | 700 | ug/l | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 |
| Ethylene dibromide (EDB) | 106-93-4 | 0.05 | ug/l | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 |
| 1,2-Dichloroethane | 107-06-2 | 5 | ug/l | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 |
| Toluene | 108-88-3 | 1000 | ug/l | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 |
| Xylene (Total) | 1330-20-7 | 10000 | ug/l | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | 1.00 | | 1.00 | ND | U | 1.00 |
| Methyl Tertiary Butyl Ether | 1634-04-4 | 20 | ug/l | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | 0.60 | J | 1.00 | ND | U | 1.00 | ND | U | 1.00 |
| Benzene | 71-43-2 | 5 | ug/l | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 |
| Cumene | 98-82-8 | 2300 | ug/l | ND | U | 2.00 | ND | U | 2.00 | ND | U | 2.00 | ND | U | 2.00 | 2.00 | J | 2.00 | ND | U | 2.00 | 0.80 | J | 2.00 | 5.00 | | 2.00 | 7.00 | | 2.00 |
| **Semi-Volatile Organic Compounds** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Pyrene | 129-00-0 | 130 | ug/l | 2.00 | J | 5.00 | ND | U | 50.00 | 170.00 | 170 | 50.00 | ND | U | 50.00 | 110.00 | | 5.00 | ND | U | 5.00 | 3.00 | J | 5.00 | 31.00 | | 5.00 | 250.00 | | 50.00 |
| Chrysene | 218-01-9 | 1.9 | ug/l | 1.00 | J | 5.00 | ND | U | 50.00 | 47.00 | | 50.00 | ND | U | 50.00 | 60.00 | | 9.00 | ND | U | 5.00 | 1.00 | J | 5.00 | 15.00 | | 5.00 | 150.00 | | 50.00 |
| Phenanthrene | 85-01-8 | 1100 | ug/l | ND | U | 5.00 | ND | U | 50.00 | ND | U | 50.00 | ND | U | 50.00 | 23.00 | | 5.00 | ND | U | 5.00 | ND | U | 5.00 | 39.00 | | 5.00 | 660.00 | | 50.00 |
| Fluorene | 86-73-7 | 1900 | ug/l | ND | U | 5.00 | ND | U | 50.00 | ND | U | 50.00 | ND | U | 50.00 | 20.00 | | 5.00 | ND | U | 5.00 | ND | U | 5.00 | 23.00 | | 5.00 | 280.00 | | 50.00 |
| Naphthalene | 91-20-3 | 100 | ug/l | ND | U | 5.00 | ND | U | 50.00 | ND | U | 50.00 | ND | U | 50.00 | 1.00 | J | 5.00 | ND | U | 5.00 | ND | U | 5.00 | 3.00 | J | 5.00 | 33.00 | J | 50.00 |
| **Metals** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Lead (Total) | 7439-92-1 | 5 | mg/l | 0.00042 | | 0.00100 | 0.00005 | | 0.00100 | 0.00038 | | 0.00100 | ND | U | 0.00100 | 0.00015 | J | 0.00100 | ND | U | 0.00100 | ND | U | 0.00100 | 0.00100 | U | 0.00100 | 0.00011 | | 0.00100 |

**Notes:**
PADEP - Pennsylvania Department of Environmental Protection
ug/l - Micrograms per liter
mg/l - Milligrams per liter
MSC - PADEP's Medium Specific Concentration for Impact to Groundwater
RL - Reporting limit (limit of quantitation)
ND - Not detected.

**Organic Qualifiers:**
Q - Qualifier
U - Analyte was analyzed but not detected.
J - Compound present. Reported value may not be accurate or precise.
UD - Compound analyzed at dilution, but not detected.
JD - Compound analyzed at dilution. Compound present, but reported value may not be accurate or precise.
D - Compound analyzed at dilution.

**Inorganic Qualifiers:**
U - Analyte was analyzed but not detected.
B - Compound present. Reported value may not be accurate or precise.

**Exceedance Summary:**
10 - Reporting limit exceeds the PADEP Non-Residential Used Aquifer MSC for Groundwater TDS<2,500.
10 - Compound exceeds the PADEP Non-Residential Used Aquifer MSC for Groundwater TDS<2,500.

**Table 2a**
**Summary of**
**Fill / Alluvium Groundwater Analytical Results**
**AOI 8 Workplan**
**Sunoco Philadelphia Refinery**
**Philadelphia, Pennsylvania**
**February 2008**

| | CAS No | PADEP Non-Residential Used Aquifer MSC for Groundwater TDS<2,500 | Sample ID<br>Sample Date<br>Sample Matrix | N-24<br>2/7/2008<br>Groundwater | | | N-55<br>2/8/2008<br>Groundwater | | | N-56<br>2/8/2008<br>Groundwater | | | N-57<br>2/7/2008<br>Groundwater | | | N-58<br>2/7/2008<br>Groundwater | | | N-60<br>2/7/2008<br>Groundwater | | | N-61<br>2/7/2008<br>Groundwater | | | N-64<br>2/8/2008<br>Groundwater | | | N-65<br>2/6/2008<br>Groundwater | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Volatile Organic Compounds** | | | **Unit** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** |
| Ethylbenzene | 100-41-4 | 700 | ug/l | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | 2.00 | | 1.00 | ND | U | 1.00 | ND | U | 1.00 | 15.00 | | 1.00 | ND | U | 1.00 | ND | U | 1.00 |
| Ethylene dibromide (EDB) | 106-93-4 | 0.05 | ug/l | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 |
| 1,2-Dichloroethane | 107-06-2 | 5 | ug/l | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 |
| Toluene | 108-88-3 | 1000 | ug/l | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | 0.80 | J | 1.00 | 0.80 | J | 1.00 | ND | U | 1.00 | 9.00 | | 1.00 | ND | U | 1.00 | ND | U | 1.00 |
| Xylene (Total) | 1330-20-7 | 10000 | ug/l | 1.00 | | 1.00 | ND | U | 1.00 | ND | U | 1.00 | 230.00 | | 1.00 | 140.00 | | 1.00 | ND | U | 1.00 | 52.00 | | 1.00 | ND | U | 1.00 | ND | U | 1.00 |
| Methyl Tertiary Butyl Ether | 1634-04-4 | 20 | ug/l | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 |
| Benzene | 71-43-2 | 5 | ug/l | 0.80 | J | 1.00 | ND | U | 1.00 | ND | U | 1.00 | 2.00 | | 1.00 | 2.00 | | 1.00 | 0.60 | J | 1.00 | 21000.00 | E | 100.00 | ND | U | 1.00 | ND | U | 1.00 |
| Cumene | 98-82-8 | 2300 | ug/l | 19.00 | | 2.00 | ND | U | 2.00 | 3.00 | | 2.00 | 4.00 | | 2.00 | 10.00 | | 2.00 | ND | U | 2.00 | 11.00 | | 2.00 | ND | U | 2.00 | ND | U | 2.00 |
| **Semi-Volatile Organic Compounds** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Pyrene | 129-00-0 | 130 | ug/l | ND | U | 50.00 | ND | U | 5.00 | 19.00 | | 10.00 | 3.00 | J | 5.00 | 3.00 | J | 5.00 | 11.00 | | 5.00 | 6.00 | | 5.00 | ND | U | 5.00 | ND | U | 25.00 |
| Chrysene | 218-01-9 | 1.9 | ug/l | ND | U | 50.00 | ND | U | 5.00 | 18.00 | | 10.00 | 2.00 | J | 5.00 | 1.00 | J | 5.00 | 11.00 | | 5.00 | 2.00 | J | 5.00 | ND | U | 5.00 | ND | U | 25.00 |
| Phenanthrene | 85-01-8 | 1100 | ug/l | ND | U | 50.00 | ND | U | 5.00 | 7.00 | J | 10.00 | ND | U | 5.00 | ND | U | 5.00 | 2.00 | J | 5.00 | ND | U | 5.00 | ND | U | 5.00 | ND | U | 25.00 |
| Fluorene | 86-73-7 | 1900 | ug/l | ND | U | 50.00 | ND | U | 5.00 | 7.00 | J | 10.00 | ND | U | 5.00 | ND | U | 5.00 | 3.00 | J | 5.00 | 3.00 | J | 5.00 | 2.00 | J | 5.00 | ND | U | 25.00 |
| Naphthalene | 91-20-3 | 100 | ug/l | ND | U | 50.00 | ND | U | 5.00 | 2.00 | J | 10.00 | ND | U | 5.00 | ND | U | 5.00 | 2.00 | J | 5.00 | 1.00 | J | 5.00 | ND | U | 5.00 | ND | U | 25.00 |
| **Metals** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Lead (Total) | 7439-92-1 | 5 | mg/l | 0.00029 | J | 0.00100 | 0.00040 | J | 0.00100 | ND | U | 0.00100 | ND | U | 0.00100 | ND | U | 0.00100 | ND | U | 0.00100 | ND | U | 0.00100 | ND | U | 0.00100 | 0.00006 | J | 0.00100 |

| | CAS No | PADEP Non-Residential Used Aquifer MSC for Groundwater TDS<2,500 | Sample ID<br>Sample Date<br>Sample Matrix | N-66<br>2/8/2008<br>Groundwater | | | N-5<br>2/6/2008<br>Groundwater | | | N-67<br>2/8/2008<br>Groundwater | | | N-73<br>2/7/2008<br>Groundwater | | | N-74<br>2/7/2008<br>Groundwater | | | N-77<br>2/7/2008<br>Groundwater | | | N-8<br>2/7/2008<br>Groundwater | | | N-85<br>2/6/2008<br>Groundwater | | | N-9<br>2/7/2008<br>Groundwater | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Volatile Organic Compounds** | | | **Unit** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** |
| Ethylbenzene | 100-41-4 | 700 | ug/l | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 |
| Ethylene dibromide (EDB) | 106-93-4 | 0.05 | ug/l | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 |
| 1,2-Dichloroethane | 107-06-2 | 5 | ug/l | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 |
| Toluene | 108-88-3 | 1000 | ug/l | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 |
| Xylene (Total) | 1330-20-7 | 10000 | ug/l | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | 1.00 | | 1.00 | ND | U | 1.00 | 0.50 | J | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 |
| Methyl Tertiary Butyl Ether | 1634-04-4 | 20 | ug/l | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 |
| Benzene | 71-43-2 | 5 | ug/l | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | 25.00 | | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 |
| Cumene | 98-82-8 | 2300 | ug/l | ND | U | 2.00 | ND | U | 2.00 | ND | U | 2.00 | ND | U | 2.00 | ND | U | 2.00 | 11.00 | | 2.00 | ND | U | 2.00 | 2.00 | | 2.00 | ND | U | 2.00 |
| **Semi-Volatile Organic Compounds** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Pyrene | 129-00-0 | 130 | ug/l | 15.00 | | 10.00 | 4.00 | J | 5.00 | ND | U | 5.00 | ND | U | 5.00 | 1.00 | J | 5.00 | ND | U | 5.00 | ND | U | 5.00 | ND | U | 5.00 | ND | U | 5.00 |
| Chrysene | 218-01-9 | 1.9 | ug/l | 11.00 | | 10.00 | 3.00 | J | 5.00 | ND | U | 5.00 | ND | U | 5.00 | ND | U | 5.00 | ND | U | 5.00 | ND | U | 5.00 | ND | U | 5.00 | ND | U | 5.00 |
| Phenanthrene | 85-01-8 | 1100 | ug/l | 10.00 | | 10.00 | 2.00 | J | 5.00 | ND | U | 5.00 | ND | U | 5.00 | ND | U | 5.00 | ND | U | 5.00 | ND | U | 5.00 | ND | U | 5.00 | ND | U | 5.00 |
| Fluorene | 86-73-7 | 1900 | ug/l | 10.00 | | 10.00 | ND | U | 5.00 | ND | U | 5.00 | ND | U | 5.00 | 2.00 | J | 5.00 | 4.00 | J | 5.00 | ND | U | 5.00 | ND | U | 5.00 | ND | U | 5.00 |
| Naphthalene | 91-20-3 | 100 | ug/l | ND | U | 10.00 | ND | U | 5.00 | ND | U | 5.00 | ND | U | 5.00 | ND | U | 5.00 | ND | U | 5.00 | ND | U | 5.00 | ND | U | 5.00 | ND | U | 5.00 |
| **Metals** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Lead (Total) | 7439-92-1 | 5 | mg/l | ND | U | 0.00100 | 1.00000 | | 0.00500 | ND | U | 0.00100 | ND | U | 0.00100 | ND | U | 0.00100 | 0.00006 | J | 0.00100 | ND | U | 0.00100 | ND | U | 0.00100 | ND | U | 0.00100 |

**Notes:**
PADEP - Pennsylvania Department of Environmental Protection
ug/l - Micrograms per liter
mg/l - Milligrams per liter
MSC - PADEP's Medium Specific Concentration for Impact to Groundwater
RL - Reporting limit (limit of quantitation)
ND - Not detected.

**Organic Qualifiers:**
Q - Qualifier
U - Analyte was analyzed but not detected.
J - Compound present. Reported value may not be accurate or precise.
UD - Compound analyzed at dilution, but not detected.
JD - Compound analyzed at dilution. Compound present, but reported value may not be accurate or precise.
D - Compound analyzed at dilution.

**Inorganic Qualifiers:**
U - Analyte was analyzed but not detected.
B - Compound present. Reported value may not be accurate or precise.

**Exceedance Summary:**
10 - Reporting limit exceeds the PADEP Non-Residential Used Aquifer MSC for Groundwater TDS<2,500.
10 - Compound exceeds the PADEP Non-Residential Used Aquifer MSC for Groundwater TDS<2,500.

# Table 2a
# Summary of
# Fill / Alluvium Groundwater Analytical Results
# AOI 8 Workplan
# Sunoco Philadelphia Refinery
# Philadelphia, Pennsylvania
# February 2008

| | CAS No | PADEP Non-Residential Used Aquifer MSC for Groundwater TDS<2,500 | Sample ID<br>Sample Date<br>Sample Matrix | N-90<br>2/8/2008<br>Groundwater | | | N-92<br>2/7/2008<br>Groundwater | | | N-94<br>2/6/2008<br>Groundwater | | | PZ-505<br>2/7/2008<br>Groundwater | | | PZ-506<br>2/8/2008<br>Groundwater | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Volatile Organic Compounds** | | | **Unit** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** |
| Ethylbenzene | 100-41-4 | 700 | ug/l | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 |
| Ethylene dibromide (EDB) | 106-93-4 | 0.05 | ug/l | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 | ND | U | 0.03 |
| 1,2-Dichloroethane | 107-06-2 | 5 | ug/l | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 |
| Toluene | 108-88-3 | 1000 | ug/l | 1.00 | | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 |
| Xylene (Total) | 1330-20-7 | 10000 | ug/l | 2.00 | | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 |
| Methyl Tertiary Butyl Ether | 1634-04-4 | 20 | ug/l | ND | U | 1.00 | ND | U | 1.00 | 0.60 | J | 1.00 | ND | U | 1.00 | ND | U | 1.00 |
| Benzene | 71-43-2 | 5 | ug/l | 2.00 | | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 | ND | U | 1.00 |
| Cumene | 98-82-8 | 2300 | ug/l | 3.00 | | 2.00 | 0.50 | J | 2.00 | ND | U | 2.00 | 2.00 | J | 2.00 | ND | U | 2.00 |
| **Semi-Volatile Organic Compounds** | | | | | | | | | | | | | | | | | | |
| Pyrene | 129-00-0 | 130 | ug/l | ND | U | 5.00 | 54.00 | | 10.00 | 2.00 | J | 5.00 | 21.00 | | 5.00 | 27.00 | | 5.00 |
| Chrysene | 218-01-9 | 1.9 | ug/l | ND | U | 5.00 | 19.00 | | 10.00 | 1.00 | J | 5.00 | 15.00 | | 5.00 | 20.00 | | 5.00 |
| Phenanthrene | 85-01-8 | 1100 | ug/l | ND | U | 5.00 | ND | U | 10.00 | ND | J | 5.00 | 2.00 | J | 5.00 | 9.00 | | 5.00 |
| Fluorene | 86-73-7 | 1900 | ug/l | ND | U | 5.00 | 28.00 | | 10.00 | ND | U | 5.00 | 3.00 | J | 5.00 | 5.00 | | 5.00 |
| Naphthalene | 91-20-3 | 100 | ug/l | ND | U | 5.00 | ND | U | 10.00 | ND | U | 5.00 | 2.00 | J | 5.00 | ND | U | 5.00 |
| **Metals** | | | | | | | | | | | | | | | | | | |
| Lead (Total) | 7439-92-1 | 5 | mg/l | ND | U | 0.00100 | ND | U | 0.00100 | ND | U | 0.00100 | 0.00031 | J | 0.00100 | 0.00008 | J | 0.00100 |

**Notes:**
PADEP - Pennsylvania Department of Environmental Protection
ug/l - Micrograms per liter
mg/l - Milligrams per liter
MSC - PADEP's Medium Specific Concentration for Impact to Groundwater
RL - Reporting limit (limit of quantitation)
ND - Not detected.

**Organic Qualifiers:**
Q - Qualifier
U - Analyte was analyzed but not detected.
J - Compound present. Reported value may not be accurate or precise.
UD - Compound analyzed at dilution, but not detected.
JD - Compound analyzed at dilution. Compound present, but reported value may not be accurate or precise.
D - Compound analyzed at dilution.

**Inorganic Qualifiers:**
U - Analyte was analyzed but not detected.
B - Compound present. Reported value may not be accurate or precise.

**Exceedance Summary:**
10 - Reporting limit exceeds the PADEP Non-Residential Used Aquifer MSC for Groundwater TDS<2,500.
10 - Compound exceeds the PADEP Non-Residential Used Aquifer MSC for Groundwater TDS<2,500.

# Table 2b
# Summary of Lower Sand Groundwater Analytical Results
# AOI 8 Workplan
# Sunoco Philadelphia Refinery
# Philadelphia, Pennsylvania
# February 2008

| | CAS No | PADEP Non-Residential Used Aquifer MSC for Groundwater TDS<2,500 | Sample ID Sample Date Sample Matrix | N-13 2/7/2008 Groundwater | | | N-19 2/6/2008 Groundwater | | | N-21 2/7/2008 Groundwater | | | N-27 2/6/2008 Groundwater | | | N-4 2/7/2008 Groundwater | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Volatile Organic Compounds** | | | **Unit** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** |
| Ethylbenzene | 100-41-4 | 700 | ug/l | ND | U | 1 | ND | U | 1 | ND | U | 1 | ND | U | 1 | 1 | | 1 |
| Ethylene dibromide (EDB) | 106-93-4 | 0.05 | ug/l | ND | U | 0.029 | ND | U | 0.029 | ND | U | 0.029 | ND | U | 0.029 | ND | U | 0.028 |
| 1,2-Dichloroethane | 107-06-2 | 5 | ug/l | ND | U | 1 | ND | U | 1 | ND | U | 1 | ND | U | 1 | ND | U | 1 |
| Toluene | 108-88-3 | 1000 | ug/l | ND | U | 1 | ND | U | 1 | ND | U | 1 | ND | U | 1 | 4 | | 1 |
| Xylene (Total) | 1330-20-7 | 10000 | ug/l | ND | U | 1 | ND | U | 1 | 3 | | 1 | ND | U | 1 | 7 | | 1 |
| Methyl Tertiary Butyl Ether | 1634-04-4 | 20 | ug/l | 2 | | 1 | ND | U | 1 | ND | U | 1 | ND | U | 1 | 0.6 | J | 1 |
| Benzene | 71-43-2 | 5 | ug/l | ND | U | 1 | ND | U | 1 | 2 | | 1 | ND | U | 1 | 71 | | 1 |
| Cumene | 98-82-8 | 2300 | ug/l | ND | U | 2 | ND | U | 2 | 10 | | 2 | ND | U | 2 | 29 | | 2 |
| **Semi-Volatile Organic Compounds** | | | | | | | | | | | | | | | | | | |
| Pyrene | 129-00-0 | 130 | ug/l | ND | U | 5 | ND | U | 5 | ND | U | 5 | ND | U | 5 | ND | U | 5 |
| Chrysene | 218-01-9 | 1.9 | ug/l | ND | U | 5 | ND | U | 5 | ND | U | 5 | ND | U | 5 | ND | U | 5 |
| Phenanthrene | 85-01-8 | 1100 | ug/l | ND | U | 5 | ND | U | 5 | ND | U | 5 | ND | U | 5 | ND | U | 5 |
| Fluorene | 86-73-7 | 1900 | ug/l | ND | U | 5 | ND | U | 5 | ND | U | 5 | ND | U | 5 | ND | U | 5 |
| Naphthalene | 91-20-3 | 100 | ug/l | ND | U | 5 | ND | U | 5 | ND | U | 5 | ND | U | 5 | ND | U | 5 |
| **Metals** | | | | | | | | | | | | | | | | | | |
| Lead (Total) | 7439-92-1 | 5 | mg/l | 0.00008 | J | 0.00100 | 0.00007 | J | 0.00100 | ND | U | 0.00100 | 0.00007 | J | 0.00100 | 0.00023 | J | 0.00100 |

| | N-38D 2/7/2008 Groundwater | | | N-50D 2/8/2008 Groundwater | | | N-69 2/6/2008 Groundwater | | | N-70 2/6/2008 Groundwater | | | N-83 2/6/2008 Groundwater | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Volatile Organic Compounds** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** | **Result** | **Q** | **RL** |
| Ethylbenzene | ND | U | 1 | ND | U | 1 | ND | U | 1 | 0.8 | J | 1 | ND | U | 1 |
| Ethylene dibromide (EDB) | ND | U | 0.029 | ND | U | 0.028 | ND | U | 0.029 | ND | U | 0.03 | ND | U | 0.029 |
| 1,2-Dichloroethane | ND | U | 1 | ND | U | 1 | ND | U | 1 | ND | U | 1 | ND | U | 1 |
| Toluene | ND | U | 1 | ND | U | 1 | ND | U | 1 | ND | U | 1 | ND | U | 1 |
| Xylene (Total) | ND | U | 1 | ND | U | 1 | ND | U | 1 | 0.7 | J | 1 | ND | U | 1 |
| Methyl Tertiary Butyl Ether | ND | U | 1 | ND | U | 1 | ND | U | 1 | ND | U | 1 | ND | U | 1 |
| Benzene | ND | U | 1 | 4 | | 1 | ND | U | 1 | ND | U | 1 | ND | U | 1 |
| Cumene | ND | U | 2 | ND | U | 2 | 5 | | 2 | 23 | | 2 | 0.8 | J | 2 |
| **Semi-Volatile Organic Compounds** | | | | | | | | | | | | | | | |
| Pyrene | ND | U | 5 | 13 | | 5 | ND | U | 5 | ND | U | 5 | 6 | | 5 |
| Chrysene | ND | U | 5 | 9 | | 5 | ND | U | 5 | ND | U | 5 | 3 | J | 5 |
| Phenanthrene | ND | U | 5 | 3 | J | 5 | ND | U | 5 | ND | U | 5 | ND | U | 5 |
| Fluorene | ND | U | 5 | ND | U | 5 | ND | U | 5 | ND | U | 5 | 1 | J | 5 |
| Naphthalene | ND | U | 5 | ND | U | 5 | ND | U | 5 | ND | U | 5 | ND | U | 5 |
| **Metals** | | | | | | | | | | | | | | | |
| Lead (Total) | 0.00005 | J | 0.00100 | 0.00012 | J | 0.00100 | 0.00012 | J | 0.00100 | ND | U | 0.00100 | ND | U | 0.00100 |

**Notes:**
PADEP - Pennsylvania Department of Environmental Protection
ug/l - Micrograms per liter
mg/l - Milligrams per liter
MSC - PADEP's Medium Specific Concentration for Impact to Groundwater
RL - Reporting limit (limit of quantitation)
ND - Not detected.

**Organic Qualifiers:**
Q - Qualifier
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UD - Compound analyzed at dilution, but not detected.
JD - Compound analyzed at dilution. Compound present, but reported value may not be accurate or precise.
D - Compound analyzed at dilution.

**Inorganic Qualifiers:**
U - Analyte was analyzed but not detected.
B - Compound present. Reported value may not be accurate or precise.

**Exceedance Summary:**
10 - Reporting limit exceeds the PADEP Non-Residential Used Aquifer MSC for Groundwater TDS<2,500.
10 - Compound exceeds the PADEP Non-Residential Used Aquifer MSC for Groundwater TDS<2,500.

**TABLE 3**
**Summary of Proposed Site Characterization Activities for AOI 8**
**AOI 8 Work Plan for Site Characterization**
**Sunoco Philadelphia Refinery**
**Philadelphia, Pennsylvania**

| Location ID | Existing | Proposed | Media | Collection of Soil Sample from 0-2 ft For Site COCs (Non-SWMU Location) | Observation for Leaded Tank Bottom Materials in Shallow Soil Borings[2] | Estimated Completion Depth for Proposed Monitoring Wells and Soil Borings | LNAPL Data Exists | COCs | Objective of Proposed Activity |
|---|---|---|---|---|---|---|---|---|---|
| N-1 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-10 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-11 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-12 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-13 | X | | Groundwater | | | | | 1 | Characterize Deep Groundwater in AOI 8 |
| N-14 | X | | Groundwater | | | | X | 1 | Characterize Groundwater in AOI 8 |
| N-15 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-16 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-17 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-18 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-19 | X | | Groundwater | | | | | 1 | Characterize Deep Groundwater in AOI 8 |
| N-20 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-21 | X | | Groundwater | | | | | 1 | Characterize Deep Groundwater in AOI 8 |
| N-22 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-23 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-24 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-25 | X | | Groundwater | | | | X | 1 | Characterize Groundwater in AOI 8 |
| N-26 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-27 | X | | Groundwater | | | | | 1 | Characterize Deep Groundwater in AOI 8 |
| N-28 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-29 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-3 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-30 | X | | Groundwater | | | | | 1 | Characterize Deep Groundwater in AOI 8 |
| N-31 | X | | Groundwater | | | | X | 1 | Characterize Groundwater in AOI 8 |
| N-32 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-34 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-35 | X | | Groundwater | | | | X | 1 | Characterize Groundwater in AOI 8 |
| N-36 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-37 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-38 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-38D | X | | Groundwater | | | | | 1 | Characterize Deep Groundwater in AOI 8 |
| N-4 | X | | Groundwater | | | | | 1 | Characterize Deep Groundwater in AOI 8 |
| N-40 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-41 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-42 | X | | Groundwater | | | | X | 1 | Characterize Groundwater in AOI 8 |
| N-43 | X | | Groundwater | | | | | 1 | Characterize Deep Groundwater in AOI 8 |
| N-44D | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-45 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-46D | X | | Groundwater | | | | | 1 | Characterize Deep Groundwater in AOI 8 |
| N-47 | X | | Groundwater | | | | X | 1 | Characterize Groundwater in AOI 8 |
| N-48 | X | | Groundwater | | | | X | 1 | Characterize Groundwater in AOI 8 |
| N-49 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-5 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-503 | X | | Groundwater | | | | X | 1 | Characterize Groundwater in AOI 8 |
| N-504 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-50D | X | | Groundwater | | | | | 1 | Characterize Deep Groundwater in AOI 8 |
| N-51 | X | | Groundwater | | | | X | 1 | Characterize Groundwater in AOI 8 |
| N-52 | X | | Groundwater | | | | X | 1 | Characterize Groundwater in AOI 8 |
| N-53 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-54 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-55 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-56 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-57 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-58 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-59 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-6 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-60 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-61 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |

**Notes:**
Final depth of well and screen placement to be determined by geologist based on field observation while completing the boring.
Field procedures will be performed in accordance with Appendix C of the Workplan.
ft bgs = feet below ground surface
COCs = Constituents of Concern
1 = Analysis of COCs listed in Table 1 of the Work Plan.
2 = Analysis for Total Lead in shallow soil only if leaded tank bottom materials are observed by the field geologist
SWMU = Solid Waste Management Unit
LNAPL = Light Non-Aqueous Phase Liquic

**TABLE 3**
**Summary of Proposed Site Characterization Activities for AOI 8**
**AOI 8 Work Plan for Site Characterization**
**Sunoco Philadelphia Refinery**
**Philadelphia, Pennsylvania**

| Location ID | Existing | Proposed | Media | Collection of Soil Sample from 0-2 ft For Site COCs (Non-SWMU Location) | Observation for Leaded Tank Bottom Materials in Shallow Soil Borings[2] | Estimated Completion Depth for Proposed Monitoring Wells and Soil Borings | LNAPL Data Exists | COCs | Objective of Proposed Activity |
|---|---|---|---|---|---|---|---|---|---|
| N-64 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-65 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-66 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-67 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-68 | X | | Groundwater | | | | X | 1 | Characterize Groundwater in AOI 8 |
| N-69 | X | | Groundwater | | | | | 1 | Characterize Deep Groundwater in AOI 8 |
| N-7 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-70 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-72 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-73 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-74 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-75 | X | | Groundwater | | | | X | 1 | Characterize Groundwater in AOI 8 |
| N-76 | X | | Groundwater | | | | X | 1 | Characterize Deep Groundwater in AOI 8 |
| N-77 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-77 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-78 | X | | Groundwater | | | | X | 1 | Characterize Groundwater in AOI 8 |
| N-79 | X | | Groundwater | | | | X | 1 | Characterize Groundwater in AOI 8 |
| N-8 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-81 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-82 | X | | Groundwater | | | | X | 1 | Characterize Groundwater in AOI 8 |
| N-83 | X | | Groundwater | | | | | 1 | Characterize Deep Groundwater in AOI 8 |
| N-84 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-85 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-86 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-87 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-88 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-89 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-9 | X | | Groundwater | | | | | 1 | Characterize Deep Groundwater in AOI 8 |
| N-90 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-91 | X | | Groundwater | | | | X | 1 | Characterize Groundwater in AOI 8 |
| N-92 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-93 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-94 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| N-95 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| PZ-201 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| PZ-202 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| PZ-203 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| PZ-204 | X | | Groundwater | | | | X | 1 | Characterize Groundwater in AOI 8 |
| PZ-300 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| PZ-500 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| PZ-501 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| PZ-502 | X | | Groundwater | | | | X | 1 | Characterize Groundwater in AOI 8 |
| PZ-503 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| PZ-504 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| PZ-505 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| PZ-506 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| PZ-507 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| RW-200 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| RW-201 | X | | NA | | | | | | No Samples - Active Recovery Well |
| RW-202 | X | | NA | | | | | | No Samples - Active Recovery Well |
| RW-203 | X | | NA | | | | | | No Samples - Active Recovery Well |
| RW-204 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| RW-205 | X | | Groundwater | | | | X | 1 | Characterize Groundwater in AOI 8 |
| RW-206 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| RW-300 | X | | NA | | | | X | | No Samples - Active Recovery Well |
| RW-301 | X | | NA | | | | | | No Samples - Active Recovery Well |
| RW-302 | X | | NA | | | | | | No Samples - Active Recovery Well |
| RW-303 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| RW-304 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| RW-305 | X | | Groundwater | | | | X | 1 | Characterize Groundwater in AOI 8 |
| RW-306 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| RW-307 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| RW-308 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| RW-309 | X | | Groundwater | | | | | 1 | Characterize Groundwater in AOI 8 |
| RW-500 | X | | NA | | | | | | No Samples - Active Recovery Well |
| RW-501 | X | | NA | | | | | | No Samples - Active Recovery Well |
| RW-502 | X | | NA | | | | | | No Samples - Active Recovery Well |
| N-98 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |

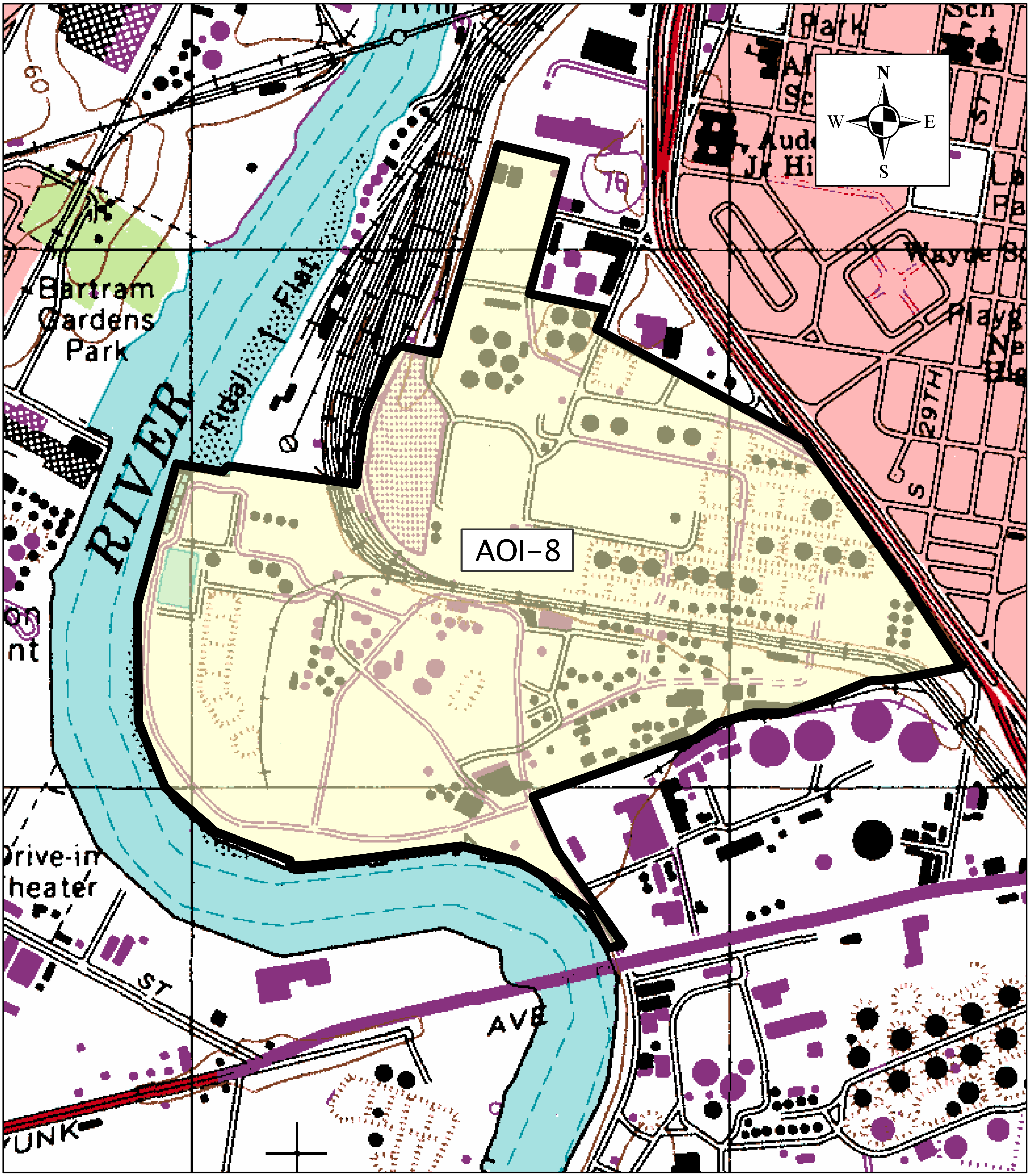
**Notes:**
Final depth of well and screen placement to be determined by geologist based on field observation while completing the boring.
Field procedures will be performed in accordance with Appendix C of the Workplan.
ft bgs = feet below ground surface
COCs = Constituents of Concern
1 = Analysis of COCs listed in Table 1 of the Work Plan.
2 = Analysis for Total Lead in shallow soil only if leaded tank bottom materials are observed by the field geologist
SWMU = Solid Waste Management Unit
LNAPL = Light Non-Aqueous Phase Liquic

**TABLE 3**
**Summary of Proposed Site Characterization Activities for AOI 8**
**AOI 8 Work Plan for Site Characterization**
**Sunoco Philadelphia Refinery**
**Philadelphia, Pennsylvania**

| Location ID | Existing | Proposed | Media | Collection of Soil Sample from 0-2 ft For Site COCs (Non-SWMU Location) | Observation for Leaded Tank Bottom Materials in Shallow Soil Borings[2] | Estimated Completion Depth for Proposed Monitoring Wells and Soil Borings | LNAPL Data Exists | COCs | Objective of Proposed Activity |
|---|---|---|---|---|---|---|---|---|---|
| N-99 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-100 | | X | Soil / Groundwater | X | | 85 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-101 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-102 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-103 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-104 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-105 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-106 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-107 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-108 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-109 | | X | Soil / Groundwater | X | | 85 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-110 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-111 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-112 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-113 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-114 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-115 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-116 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-117 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-118 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-119 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-120 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-121 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-122 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-123 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-124 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-125 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-126 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-127 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-128 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-129 | | X | Soil / Groundwater | X | | 85 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-130 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-131 | | X | Soil / Groundwater | X | | 85 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-132 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-133 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-134 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-135 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| N-136 | | X | Soil / Groundwater | X | | 25 ft bgs | | 1 | Characterize Soil and Groundwater in AOI 8 |
| BH-08-01 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-02 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-03 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-04 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-05 | | X | Soil | | X | 8 ft bgs | | 2 | Characterize Soil in AOI 8: SWMU 2 |
| BH-08-06 | | X | Soil | | X | 8 ft bgs | | 2 | Characterize Soil in AOI 8: SWMU 2 |
| BH-08-07 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-08 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-09 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-10 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-11 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-12 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-13 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-14 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-15 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-16 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-17 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-18 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-19 | | X | Soil | | X | 8 ft bgs | | 2 | Characterize Soil in AOI 8: SWMU 2 |
| BH-08-20 | | X | Soil | | X | 8 ft bgs | | 2 | Characterize Soil in AOI 8: SWMU 2 |
| BH-08-21 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-22 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-23 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-24 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-25 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-26 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-27 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-28 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-29 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-30 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-31 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-32 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-33 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-34 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-35 | | X | Soil | X | | 2 ft bgs | | 1 | Characterize Soil in AOI 8 |
| BH-08-36 | | X | Soil | | X | 8 ft bgs | | 2 | Characterize Soil in AOI 8: SWMU 2 |
| BH-08-37 | | X | Soil | | X | 8 ft bgs | | 2 | Characterize Soil in AOI 8: SWMU 2 |

**Notes:**
Final depth of well and screen placement to be determined by geologist based on field observation while completing the boring.
Field procedures will be performed in accordance with Appendix C of the Workplan.
ft bgs = feet below ground surface
COCs = Constituents of Concern
1 = Analysis of COCs listed in Table 1 of the Work Plan.
2 = Analysis for Total Lead in shallow soil only if leaded tank bottom materials are observed by the field geologist
SWMU = Solid Waste Management Unit
LNAPL = Light Non-Aqueous Phase Liquic

# FIGURES




USGS Topographic Map, Philadelphia, PA. Quadrangle, USGS 1995

Sunoco, Inc. (R&M)
Philadelphia Refinery
3144 Passyunk Avenue
Philadelphia, PA. 19145

Figure 1: Site Location Map: AOI 8
AOI 8 Work Plan for Site Characterization
Philadelphia Sunoco Philadelphia Refinery Pennsylvania

| Job Number | Scale: 1" = 800' | Date |
|---|---|---|
| 2574601 | 0 400 800 Feet | April 8, 2008 |

Q:\Data6\2574601\ArcGIS\MapDocuments\AOI 8 Workplan\Report Figures\Figure 1- AOI 8 Boundaries.mxd


N

W E

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## Legend

**Proposed Activities**

- Shallow Soil Boring Locations (0-2 feet)
- New Shallow/Intermediate Groundwater Monitoring Well Locations
- New Shallow/Intermediate Groundwater Monitoring Well Locations with Deep Soil Borings

**Existing Features**

- Existing Monitoring Point
- Existing Recovery Well
- Lead Weathering Pad Solid Waste Management Unit (SWMU 2)
- AOI Boundary

Figure 2: Summary of Proposed Site Characterization Activities for AOI 8
AOI 8 Work Plan for Site Characterization
Sunoco Philadelphia Refinery
Philadelphia, Pennsylvania

Sunoco, Inc. (R&M)
Philadelphia Refinery
3144 Passyunk Avenue
Philadelphia, PA.
19145

0 230 460 Feet

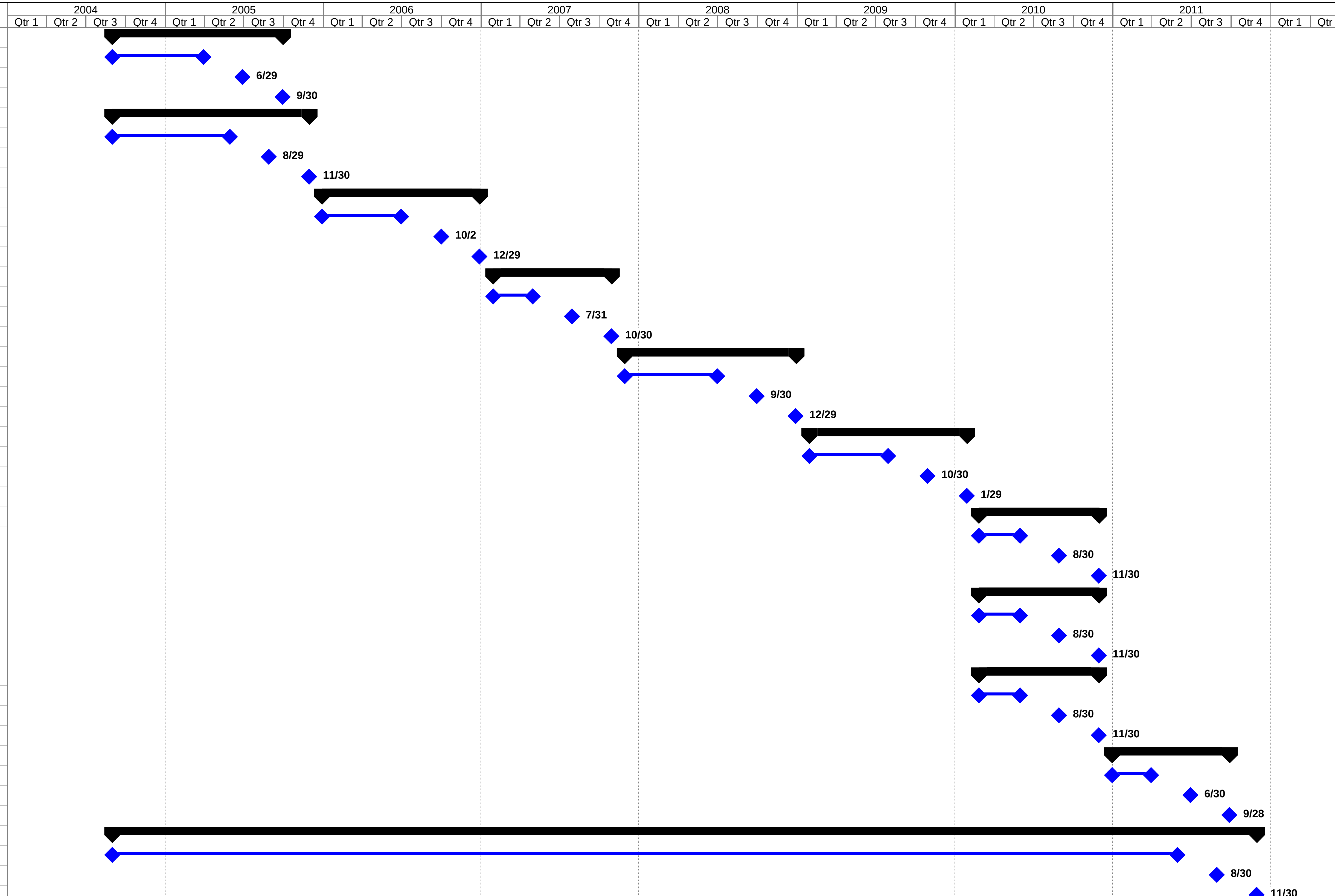
# APPENDIX A

# REVISED PHASE II CORRECTIVE ACTION ACTIVITIES SCHEDULE

# Figure 19

## Phase 2 Corrective Action Activities

| ID | Task Name |
|---|---|
| 1 | **AOI 1** |
| 2 | Characterization |
| 3 | Submittal of Site Characterization Report |
| 4 | PADEP Comments |
| 5 | **AOI 4** |
| 6 | Characterization |
| 7 | Submittal of Site Characterization Report |
| 8 | PADEP Comments |
| 9 | **AOI 6** |
| 10 | Characterization |
| 11 | Submittal of Site Characterization Report |
| 12 | PADEP Comments |
| 13 | **AOI 5** |
| 14 | Characterization |
| 15 | Submittal of Site Characterization Report |
| 16 | PADEP Comments |
| 17 | **AOI 8** |
| 18 | Characterization |
| 19 | Submittal of Site Characterization Report |
| 20 | PADEP Comments |
| 21 | **AOI 9** |
| 22 | Characterization |
| 23 | Submittal of Site Characterization Report |
| 24 | PADEP Comments |
| 25 | **AOI 3** |
| 26 | Characterization |
| 27 | Submittal of Site Characterization Report |
| 28 | PADEP Comments |
| 29 | **AOI 2** |
| 30 | Characterization |
| 31 | Submittal of Site Characterization Report |
| 32 | PADEP Comments |
| 33 | **AOI 7** |
| 34 | Characterization |
| 35 | Submittal of Site Characterization Report |
| 36 | PADEP Comments |
| 37 | **AOI 10** |
| 38 | Characterization |
| 39 | Submittal of Site Characterization Report |
| 40 | PADEP Comments |
| 41 | **AOI 11** |
| 42 | Characterization |
| 43 | Submittal of Site Characterization Report |
| 44 | PADEP Comments |




Project: Figure 19 Phase 2 Corrective
Date: Mon 10/9/06

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Task | Progress | Summary | External Tasks | Deadline |
| Split | Milestone | Project Summary | External Milestone | |

# APPENDIX B

# PA-ONE CLEANUP PROGRAM MEETING LETTER

**Research and Development**

**Sunoco Inc.**
100 Green Street
PO Box 426
Marcus Hook PA 19061
610 859 1700

December 2, 2005

Mr. Paul Gotthold
Chief, Pennsylvania Operations Branch
U.S. Environmental Protection Agency
Region 3 Regional Office
1650 Arch Street
Philadelphia, PA 19103-2029

Mr. Dave Hess
Chief, Voluntary Cleanup and Standards Section
PADEP
Rachel Carson State Office Building
P.O. Box 8471
Harrisburg, PA 17105-8471

**SUBJECT: One Clean-up Program Applicability for Sunoco Philadelphia Refinery**

Dear Gentlemen:

Thank you for taking the time to meet with us regarding the subject site. As we discussed, Sunoco, Inc. (R&M) ("Sunoco") is interested in the applicability of the One-Clean-Up Program to streamline the remediation program at our Philadelphia Refinery under the EPA RCRA program, the PADEP Act 2 program, and the existing PADEP Consent Order. It is our understanding that both of you and your respective agencies also see a benefit to merging the remediation obligations under the various programs under one consistent approach that has been in place and working for a number of years for our facility. We agreed that the One-Clean-Up program would work best if it covered the entire Philadelphia Refinery, including areas that are under separate corrective action permits, even though report submittals, field work, and remedial decision making is made on a area-by-area basis as defined in the Consent Order. Sunoco believes that this approach maintains the flexibility, and prioritization approach that is a hallmark of our existing remedial program, while gaining the benefits of having the entire facility dealt with under the overall One-Clean-Up plan.

As a result of our discussions we identified the following approach:

a) Sunoco would submit a Notice of Intent to Remediate (NIR) under the PADEP Act 2 program. The NIR would specifically reference the Consent Order, including its Area of Interest approach.
b) EPA will provide copies of previous letters signifying approval with the Act 2 process from other sites that have been through the One-Cleanup program.
c) EPA will provide to Sunoco a copy of a recently completed Corrective Action permit for another facility.
d) Sunoco will work on a first draft of a proposed corrective action permit that would cover the Philadelphia Refinery.

Sunoco believes the meeting was fruitful and that the One-Clean-up program offers some significant advantages to move the facility's remedial programs towards clean-up. We look forward to working cooperatively together on this important program. We would appreciate confirmation from both of you that you agree with the above approach.

Thank you again for taking the opportunity to discuss these issues with us. I have attached the sign-in sheet from our meeting. Please call me at 610-859-1628 with any questions.

Very truly yours,

Steven Coladonato, PE
Remediation Services Manager
Sunoco, Inc. (R&M)

cc: S. O'Neil, PADEP
W. Payne, PADEP
D. Burke, PADEP
H. Lee, USEPA
J. Oppenheim, Sunoco, Inc.
E. Ciechon, Sunoco, Inc.
C. Costello, Langan
J. Hanna, Langan

4100-FM-SE0026 5/97

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# COMMONWEALTH OF PENNSYLVANIA
# DEPARTMENT OF ENVIRONMENTAL PROTECTION

Southeast Regional Office
Lee Park, Suite 6010
555 North Lane, Conshohocken, PA 19428

at Langan's Office
30 South 17th St
Philadelphia, PA

**Date:** Nov 22, 2005 **MEETING LOG** **Subject:** Sunoco - Philly Refinery

**Programs Attending:** RD __ AQC __ RP __ CRC __ ECP __ WQM __ WSM __ SWM __ ERC __ ADM __

| NAME | TITLE | PROGRAM/COMPANY | PHONE # |
|---|---|---|---|
| Colleen Costello | | Langan | 2154397888 |
| DAVID BURKE | | PADEP | 484-250-5822 |
| DAVE HESS | | PADEP | 717-783-9480 |
| Jason Hanna | | Langan | 215-491-6500 |
| Steve Coladonato | | Sunoco | 610-859-1620 |
| Hon Lee | | EPA Reg 3 | 215-814-3419 |
| Paul Gotthold | | EPA Reg 3 | 215-814-3410 |
| ~~WALTER PAYNE~~ | | ~~PADEP~~ | ~~484-250-5791~~ |
| Jim Oppenheim | | SUNOCO | (610) 299-5136 |
| ED CIECIYON | | SUNOCO | (215) 977-6139 |
| Steve Oneil (by phone) | | PADEP | |

| NAME | TITLE | PROGRAM/COMPANY | PHONE # |
|---|---|---|---|

# APPENDIX C

# FIELD PROCEDURES

**APPENDIX C**
**FIELD PROCEDURES**
**AOI 8 WORK PLAN FOR SITE CHARACTERIZATION**
**SUNOCO PHILADELPHIA REFINERY**
**PHILADELPHIA, PENNSYLVANIA**

## C.1. LIQUID LEVEL ACQUISITION

**Responsible Personnel:** Technicians and Geologists

**Training Qualifications:**

All field personnel involved in liquid level acquisition shall have, as a minimum, completed OSHA 40 HOUR HAZWOPER training and completed the 3-day minimum field training requirements as specified within the Corporate Health and Safety Plan. Prior to solo performance of liquid levels, all field personnel will have performed a minimum of three site visits under the direct supervision of experienced personnel.

**Health and Safety Requirements:**

**Personal Protective Equipment (PPE) Required**:

Level D attire including steel toe/steel shank boots. Based on previous site visits or current air monitoring results, Level C attire may be required. The PPE required to upgrade to Level C may include: nitrile gloves, disposable outerboots, Tyvek coveralls, and a respirator. Safety glasses or hard hats may also be required in certain areas.

**Site Controls:**

Safety cones and or caution tape should be used in high traffic areas. The "Buddy system" may also be employed in high traffic areas.

**Potential Hazards:**

Traffic, pinch and trip, chemical (airborne and physical contact) and biological. Additional hazards are mentioned in site-specific HASP.

**Materials and Equipment Necessary for Task Completion:**

Electronic oil/water interface probe or conductivity water line, decontamination supplies (Liquinox, deionized-distilled water, appropriate containers, scrub brush, and sorbent pads or paper towels), air monitoring instrument (optional, based on previous site visits).

**Methodology:**

The task involves the deployment of a liquid sensing probe into a well (in most cases), recording the reading, and decontaminating the probe. The recorded field readings can then be utilized for one of several applications including: well sampling, water table gradient mapping, separate-phase hydrocarbon occurrence, thickness, and or gradient mapping, and various testing procedures.

The proper procedure for liquid level acquisition from a well is as follows:

1) The wells should be gauged in order of least to most contaminated based on existing sampling data or separate-phase hydrocarbon occurrence.
2) The gauging instrument is decontaminated prior to initial deployment and after each well to prevent cross contamination between wells.
3) Decontamination procedures include the following steps:

    a) Remove gross contaminants with sorbent pad or towel.
    b) Rinse/scrub equipment with water.
    c) Scrub equipment in Liquinox@/deionized-distilled water solution.
    d) Double rinse with deionized-distilled water.
    e) Air dry.

4) The well(s) to be gauged may need to be marked off with safety cones and or caution tape in order to protect personnel from auto traffic; the "Buddy system" may also be employed.
5) The manhole cover is then lifted off of the well head. A pry bar may be needed to prevent personal injury in the case of large manhole covers.
6) The probe is lowered into the well until the instrument signals contact with liquid.
7) The corresponding reading is recorded when the instrument signals either water or product. A clear bailer may be used to verify the existence or approximate amount and appearance of product.
8) The probe is then retracted from the well and decontaminated accordingly.
9) The well is then secured appropriately.
10) Note the start and stop time for gauging round in the field book.

## C.2. GROUNDWATER MONITORING PROCEDURES

**Responsible Personnel:** Technicians and Geologists

**Health and Safety Requirements**:

Site specific HASP must be completed and reviewed by field personnel. Ambient air monitoring will be performed quarterly at all treatment areas to determine the necessity of PPE upgrade. As a minimum, level "D" attire will be worn.

**Training Qualifications:**

All field personnel involved in groundwater monitoring shall have, as a minimum completed OSHA 40 HOUR HAZWOPER training and completed the 3 day minimum field training requirements. Prior to groundwater monitoring, all field personnel will have sampled a minimum of three sites under the direct supervision of experienced personnel. Field personnel will also have experience in vapor monitoring techniques and sampling equipment decontamination.

**Materials and Equipment Necessary for Task Completion:**

A list of equipment required to access, gauge, purge, and sample site monitoring wells is presented below. Also listed are materials necessary to store, label, preserve, and transport groundwater samples.

- Current site map detailing well locations.
- Field data book for recording site data.
- Liquid level gauging device (graduated, optical interface probe).
- Keys and tools to provide well access.
- Appropriate sample containers and labels: volatile samples will be collected in laboratory provided 40 milliliter (ml) glass vials with plastic caps fitted with Teflon ® lined septa; all sample bottles will be laboratory sterilized and will contain the appropriate preservative, if applicable.
- Appropriate well purging apparatus as determined by volume of groundwater to be purged and compounds to be analyzed.
- Teflon ® (or equivalent) bottom-loading bailer to extract groundwater sample.
- Clean nylon or polypropylene bailer cord.
- Disposable nitrile sampling gloves.
- Decontamination supplies.
- Calibrated five-gallon bucket and watch or stopwatch to determine discharge rate during purging.
- Blank chain-of-custody forms.
- Cooler and ice for sample preservation.

**Methodology for Three Well Volume Sampling:**

Prior to actual site visitation for the groundwater sampling event, the following data will be reviewed to ensure proper preparation for field activities:

- Most recent liquid level data from all wells.
- Most recent analytical data from all wells to determine gauging and sampling sequence.
- Well construction characteristics.

Each monitoring well to be sampled will be gauged to obtain liquid level data immediately prior to initiation of the sampling process. Refer to Liquid Level Gauging SOP for appropriate well gauging procedures.  Liquid level data will be recorded in a field book. Should free-phase petroleum product be detected by the gauging process and verified through inspection in a pre-cleaned acrylic bailer, groundwater sampling will not be conducted at that location.

The sampling procedure will be initiated by purging from the well a minimum of three well volumes, except in cases where the well is pumped dry, as referenced below. Well purging is performed to remove stagnant water and to draw representative water from the aquifer into the well for subsequent sampling and analysis for the established parameters. In extreme cases where a well is pumped dry and/or shows little recharge capacity, the well will be evacuated once prior to sample procurement. Well volume calculations will be based on total well depth as determined during well installation and depth-to-water measurements obtained immediately prior to sampling.

Well purging is performed with various equipment including 1) a dedicated bailer for hand bailing low volumes of water, 2) a surface mounted electric centrifugal pump with dedicated polyethylene tubing, or 3) submersible pump (when the depth to water is greater than 20 feet) with dedicated polyethylene tubing. During pumping, the intake will be placed directly below the static water surface and slowly lowered during the purging process. This procedure may not prove necessary in low-yielding wells but is important in high-yielding, permeable strata where an intake initially placed deep in a well may draw laterally and have little influence in exchanging water from shallower depths within the well bore.

Flow rate during well purging will be approximated by the bucket and stop watch method. The duration of pumping required to remove three well volumes will be calculated directly from this flow rate. After purging, the well will be allowed to recover for a period of approximately two hours prior to sample collection. This action will permit a consistent groundwater flux into each well and allow for VOC stabilization prior to sample extraction. All fluids removed during purging will be treated on-site with activated carbon.

The sequence of obtaining site groundwater samples will be based upon available historical site data for existing wells and soil organic vapor analyzer (OVA) readings for newly installed wells. Site wells will be sampled in order from the lowest to highest concentration of water quality indicator parameters based upon the most recent available set of laboratory analyses to reduce the potential for sample cross-contamination. Groundwater samples will not be obtained for analysis from any well containing a measurable free product layer.

The following sequence of procedures will be implemented for the collection of groundwater samples from monitoring wells.

1) Establish a clean work area where sampling equipment will not come in contact with the ground or any potentially contaminated surfaces.
2) Use a laboratory, pre-cleaned Teflon@ sampling bailer for each well.
3) Don an unused, clean pair of nitrile gloves.
4) Attach an appropriate length of unused, clean nylon or polypropylene cord to the designated sampling bailer.
5) Select appropriate laboratory-sterilized sample containers.
6) Slowly lower sampling bailer into well until water surface is encountered; continue to lower the sampling bailer into the standing water column to one foot below the water surface.
7) Retrieve bailer at a steady rate to avoid excess agitation.
8) Visually inspect bailed sample to ensure that no free product or organic detritus has been collected.
9) Uncap first designated sample vial and fill from bailer as rapidly as possible but minimizing agitation; secure septum and lid.
10) Inspect sealed sample for entrapped air; if air is present within sample vial. Remove lid and repeat vial filling, sealing and inspection process until no air is present.

11) Repeat Steps 9 and 10 for the second designated vial; all volatile parameter samples will be collected in duplicate.
12) Complete and attach labels to sample containers noting sample collector, date, time, and location of sample; record same data in field book.
13) Place samples in ice-filled cooler in such a manner as to avoid breakage. Samples collected for VOC analysis will be maintained at a temperature of 4°C.

Discard gloves and bailer cord and move to next sample location.

**Methodology for Low-Flow Purging and Sampling:**

For wells that will be Low-Flow purged and sampled, the USEPA Region III Bulletin QAD023: *Procedure for Low-Flow Purging and Sampling of Groundwater Monitoring Wells* will be followed. The following data will be reviewed for each well in order to set the pump intake for the low flow sampling:

- Soil boring (lithologic) log and continuous soil sample PID;
- Well construction log showing the screened interval;
- Identification of the most permeable zone screened by the well;
- Approximate depth to static water;
- Proposed pump intake setting; and,
- Technical rationale for the pump intake setting, preferably across from the most impacted/contaminated subsurface interval.

**Equipment**

Adjustable rate, submersible, bladder pumps in conjunction with Teflon or Teflon-lined polyethylene tubing for purging and sampling will be used. The tubing diameter will be between 3/16-inch to ½-inch inner diameter and the length of the tubing extended outside the well will be minimized. Flow through cells will be used to evaluate parameters during sampling. Monitoring well information, equipment specifications, water level measurements, parameter readings, and other pertinent information will be recorded during monitoring well purging and sampling.

**Sampling Procedure**

The following protocol details the low-flow sampling procedure that will be used for sampling the monitoring wells.

1. <u>PID Screening of Well</u>. A PID measurement will be collected at the rim of the well immediately after the well cap will be removed and recorded on the sampling form.

2. Depth to Water Measurement. A depth to water measurement will be collected and recorded. To avoid disturbing accumulated sediment and to prevent the inadvertent mixing of stagnant water, measuring the total depth of the well will be done at the completion of sampling on an annual basis.

3. Low Stress Purging Startup. Water pumping will commence at a rate of 100 to 400 milliliters per minute (mL/min). This pumping should cause very little drawdown in the well (less than 0.2-0.3 feet) and the water level should stabilize. Water level measurements are made continuously and will be recorded in milliliters per minute on the sampling form.

4. Low Stress Purging and Sampling. The water level and pumping rate will be monitored and recorded every five minutes during purging, and any pumping rate adjustments will be recorded. During the early phase of purging, emphasis will be placed on minimizing and stabilizing pumping stress, and recording any necessary adjustments. Adjustments, when necessary, will be made in the first 15 minutes of purging. If necessary, pumping rates will be reduced to the minimum capabilities of the pump to avoid well dewatering. If the minimal drawdown exceeds 0.3 feet, but the water level stabilizes above the pump intake setting, purging will continue until indicator field parameters stabilized, as detailed in Step 5 below. If the water level drops below the pump intake setting at the absolute minimum purge rate, the pump will remain in place and the water level will be allowed to recover repeatedly until there will be sufficient water volume in the well to permit the collection of samples.

5. Indicator Field Parameters Monitoring. During well purging, indicator field parameters (DO, turbidity, pH, specific conductance, and redox potential) will be monitored every five minutes (or less frequently, if appropriate). Purging will be considered complete and sampling began when all the aforementioned indicator field parameters had stabilized. Stabilization will be achieved when three consecutive readings, taken at five (5) minute intervals (or less frequently, if appropriate), are within the following limits:

   - DO (±10 percent)
   - turbidity (±10 percent)
   - specific conductance (±3 percent)
   - pH (± 0.1 unit)
   - redox potential [Eh] ±10 mv)

Temperature and depth to water will be also monitored during purging. Should any of the parameter-reading components of the flow-through meter fail during sampling, the sampling team will attempt to locate a replacement flow-through meter. If none is available, the sampling team will measure that parameter with an individual criteria meter. Any other field observations relating to sample quality, such as odor, foaming, effervescence, and sheens, will also be recorded on the sampling form.

6. Collection of Ground Water Samples. Water samples for laboratory analyses will be collected before the groundwater had passed through the flow-through cell by either using a by-pass assembly or by temporarily disconnecting the flow-through cell. All sample containers will be filled by allowing the pump discharge to flow gently down the inside of

the container with minimal turbulence. During purging and sampling, the tubing remains filled with water in order to minimize possible changes in water chemistry upon contact with the atmosphere. Methods employed to ensure that the outlet tubing will be filled include (i) adjusting the tubing angle upward to completely fill the tubing and (ii) restricting the diameter of the tubing near the outlet of the tubing.

The order in which samples will be collected is as follows:

- Volatile organics
- Gas sensitive (e.g., $Fe^{+2}$, $CH_4$, $H_2S$/HS)
- Base/Neutrals or PAHs
- Total Petroleum Hydrocarbons
- Total metals
- Dissolved metals
- Cyanide
- Sulfate and chloride
- Nitrate and ammonia
- Preserved inorganic
- Non-preserved inorganic
- Bacteria

**Decontamination Requirements**:

Numerous practices are employed throughout the processes of site investigation and sampling to assure the integrity of the resulting data. Of particular significance to the procedures of groundwater measurement and sampling is the limitation, whenever possible, of materials inserted into a well bore and, even more importantly, of materials transferred from well to well.

Many items can be discarded between well sampling and/or gauging locations without significantly impacting project costs. Dedicated sampling equipment which can be discarded between well sampling locations without significantly impacting project costs, will be used whenever possible to preclude decontamination requirements. Sampling equipment included in this category are Teflon ® bailers, nitrile gloves, and bailer cord. However, other investigative and sampling equipment, including such items as liquid level probes, must be reused from well to well.

The danger in multi-well equipment applications lies in the potential of cross-contamination. While the threat of cross-contamination is always present, it can be minimized through the implementation of a consistent decontamination program during sensitive site measurement and data collection activities. The decontamination procedure is outlined below:

All site equipment used in a multi-well capacity will be decontaminated immediately prior to initial use and between each well. Standard site decontamination procedures for the optical interface probes between wells will be performed according to the following schedule:

- Initial rinse with clean tap water to remove excess residuals.
- Scrub equipment with sponge or clean, soft cloth in a distilled water/Liquinox@ (or equivalent) solution.
- Double rinse with deionized/distilled water.

Rinse water generated during decontamination procedures will be treated on-site by passing the water through a bucket filled with activated carbon prior to disposal.

## C.3. SOIL SAMPLING & WELL INSTALLATION

**Responsible Personnel:** Geologist

**Training Qualifications**: All field personnel supervising drilling activities shall have completed OSHA 40-Hour training, and three days of field training. Personnel supervising the well installation shall have observed drilling procedures for a minimum of three under the direct supervision of experienced personnel. Field personnel will have experience in operating the following field equipment: interface probe and photo-ionization detector (PID). Personnel should be able to describe soils encountered during drilling for generation of well logs.

**Health and Safety Requirements**:

A site specific HASP must be completed and reviewed by all field personnel. Prior to deploying a rig to the site, a utility call must be made (i.e. Pennsylvania One-Call) to allow mark-out of known subsurface utilities and associated laterals proximal to the site. Site plans, if available, should be reviewed to document and avoid the location of on-site utilities. No drilling should occur on retails sites within the exclusion zone. This zone is defined as the area between the pumps, the tank field and the station building. The area is excluded from drilling activities due to the likely occurrence of subsurface petroleum distribution lines. After review of all known mapped and marked utilities, a site reconnaissance will be performed to document the location of utility meters and storm sewer drains. In addition, the location of overhead utilities must be documented. After completing the subsurface and overhead utility review, the area to drill may be observed as clear or the location may be adjusted to a “clear” location.

Once the drilling location is established, the area must be marked with cones to alert area traffic of the work area. Other health and safety concerns include slip/trip hazards, working with heavy equipment and overhead work hazards. During drilling activities, a minimum of protective work gloves, steel toed boots, hard hats, and safety goggles must be worn.

A final health and safety requirement includes hand clearing the borehole, prior to advancing the borehole with the drill rig. To ensure the safety of workers, the borehole will be cleared by hand or air knife, to depth of 5 feet below ground surface. This will serve to clear the area of utilities, prior to drilling.

**Decontamination Requirements:**

All down-hole equipment must be steamed cleaned prior to drilling at each boring/well location. All soil sampling equipment must be cleaned with detergent and rinsed with distilled water prior to deployment into the borehole. All well construction materials (i.e. PVC well casing, PVC well screen, sand pack, bentonite seal) should be clean and dedicated to each hole.

**Methodology for Borings outside RCRA Areas in AOI 8:**

1) Borehole Advancement

During soil sampling or well installation activities, a borehole is advanced into the unconsolidated subsurface materials or bedrock via a drill rig (or similar). Various types of drilling methods could be deployed to advance the hole. A description of each drilling method is included below:

a) Hollow Stem Auger

A spiral tool form is used to move material from the subsurface to the surface. A bit at the bottom cuts into the subsurface material. Spiral augers on outside convey the material to the surface while spinning. The center of the auger is hollow like a straw when the inner drive rods and plug are removed. During drilling or formation cutting, the center is filled with rods connected to a plug at the bottom bit. Once the desired drilling depth is reached, the center plug and rods can be pulled out, leaving the hollow augers in place. The hollow augers hold the borehole to remain open for sediment sampling and well installation.

b) Air Rotary

A drill bit at the bottom of rods is used to cut into the subsurface material. Air injected into the drill rods escapes through small holes in the drill bit and conveys the drill cuttings to the surface.

c) Geoprobe®

The geoprobe® sampling allows collection of soil by directly pushing (through hydraulic hammering) a sampling device lined with a plastic macrocore into the soil column.

d) Hand Auger

A stainless steel or aluminum hand auger will be physically advanced to the desired soil sampling depth.

2) Soil Sampling

Soil samples will be obtained for lithologic logging and laboratory analysis for chemical contaminants with one of three different sampling devices: Split barrel spoon sampler, hand auger or Geoprobe® soil sampler. For either method, the sampling devices are lowered through the hollow-stem augers or open borehole to allow sampling of the undisturbed sediments below the auger bit. Soil samples will be collected at intervals which appear to be visually impacted or from intervals which exhibit the highest deflections on the screening device (PID or similar).

a) Split barrel spoon sampler (split spoon)

The split spoon sampler will be driven into the soil column in accordance with ASTM Standard Method D1586 (Reference A6, Appendix E). Soil sampling by split barrel spoon will entail drilling a borehole with a hollow-stem auger to the desired sampling depth (standard five foot intervals). After augering to the desired depth, slowly and carefully lower the split barrel spoon sampler attached to the drill rod extension into the borehole. Drive the sampler into the soil by repeated blows from a 140 Lb. hammer with 30 inch travel. Record the blow counts required to drive the split spoon sampler each successive six inch interval. Remove sampler for borehole, split barrel open, remove soil sample utilizing a stainless steel knife to trim the top and edges of the sample and containerize sample in appropriate sample jar.

b) Geoprobe®

The geoprobe® liner is dedicated to each soil sampling interval. After retrieval of the sample, the liner may be sliced open and the soil sample can be logged and containerized in the appropriate sample jar. During shallow soil sampling from fine-grained sediments, the geoprobe® can advance the sampler directly into the ground, without the advance of an augered borehole.

c) Hand Auger

The hand auger allows for soil from the desired interval to be collected directly by removing the soil column that is contained in the auger portion of the device.

All soil samples collected for Site COC's will be collected using discrete soil sampling methods such as Geoprobe® macro cores or split spoons samplers.

**Methodology for Borings Around the Perimeter of Former Leaded Tank Bottoms Weathering Pad, SWMU 2, in AOI 8:**

1) Borehole Advancement

During soil sampling activities at SWMU 2, boreholes will be advanced in areas surrounding the perimeter of the existing concrete pad via a geoprobe® or hand auger. Actual leaded tank bottom materials are distinguished by distinctive rust/red to black, metallic mostly oxidized scale materials. Leaded tank bottoms are also sometimes in a matrix of petroleum wax sludge. Borings will be completed around the perimeter of SWMU 2 to a depth of two feet below ground surface. If materials encountered match the physical description stated above, they will be delineated through additional borings and sampling.

2) Soil Sampling

Soil samples will be obtained for lithologic logging and laboratory analysis for chemical contaminants with one of two different sampling devices: Geoprobe® soil sampler or hand auger. Soil samples will be collected at intervals which appear to be visually impacted or from intervals which exhibit the highest deflections on the screening device (PID or similar). If soil samples are collected in the SWMU area and exhibit total lead concentrations exceeding 450 mg/kg (Act 2 non-residential MSC for lead), then the samples will be submitted for hazardous characteristic analysis under RCRA.

3) Well Construction

After drilling to the desired depth or the desired interval, permanent monitoring wells can be installed to allow groundwater sampling. In general, wells are constructed with slotted screen, which allows groundwater to flow into the well at the desired monitored interval and well casing, which restricts groundwater flow into the well from undesired interval. In most cases the well materials are constructed of PVC. In conditions where the shallowest groundwater interval is monitored, a single case construction monitoring well is installed. In conditions where multiple water bearing units occur and deep groundwater conditions are selected for monitoring, a double cased well is installed.

a) Single Casing Construction

The construction details of a monitoring well are determined by soil type, depth to groundwater and relative fluctuation of groundwater level. After drilling to the desired depth, a monitoring well is constructed for installation into the evacuated borehole. The well consists of a bottom cap, a length of screen and length of well casing. To determine the length of screen used, seasonal groundwater table or tidal fluctuations should be considered to allow the water table to intercept the well screen throughout the year. The assembled well is then inserted into the borehole.

The annular space between the well screen and subsurface is filled with a sand pack, which consists of clean, sorted sand. The sand pack allows water flow into the well but acts as a filter to prevent subsurface sediments from silting in the well. The sand pack extends one to two feet above the top of well screen. Above the sand pack, a seal is installed in the annular space between the well casing and the subsurface. The seal is comprised of hydrated bentonite and prevents surface water from infiltrating the well screen. Above the well seal, the annular space is backfilled with drill cuttings or cement. A cap is placed on the top of the well to further prevent infiltration of the surface water. The top of the well is protected with either a stand-up pipe or a locking, flush mount box.

b) Double Casing Construction

In cases where multiple water bearing zones occur, a double case well is installed to allow monitoring of the deeper water bearing zones. Construction of a double cased well is similar to that of a single case well; however, to prevent groundwater infiltration from shallower water bearing zones, a second casing is installed. This type of construction requires drilling two different diameter boreholes.

During drilling through the shallower groundwater zones, large diameter augers/bits are used to create a large diameter borehole. The borehole is advanced through the shallower water bearing area which will not be monitored. An outer casing is installed to seal the deeper monitoring well from infiltration from the shallow water bearing zones. After the outer casing is installed, the borehole is advanced deeper with smaller diameter auger/bit. The outside diameter of second augers fit within the inside diameter of the outer casing. The borehole is advanced to allow monitoring of the deeper water bearing zone. Once the desired depth is obtained, a monitoring well is installed within the outer casing, using similar methods as described in the single casing construction (3a, above). The outside casing prevents shallow groundwater infiltration into the well. The inside casing prevents surface water infiltration into the well.

4) Soil Cutting Handling

Cuttings generated from drilling will be containerized or stock-piled, undercover, until appropriate disposal is determined. In the case the soils are not impacted, the cuttings may remain on-site. Impacted soils will be removed using appropriate hazardous waste handling procedures and disposed of with an approved hazardous waste handler.

5) Well Development

After installation, monitoring wells are developed to remove residual sediments within the well and annular space. Water is pumped from the well a low flow rate (to minimize turbulence within the well and associated sand pack) until groundwater flowing from the well appears relatively free of sediments.

**Documentation:**

All site activities should be detailed in the site investigators fieldbook. The entry shall include the date, time, weather, address, and persons present on-site. In addition, data required to create well construction logs or boring logs (if no well is constructed) should be collected. This data includes soil type, relative moisture content, depth of water table, observed impact, soil screening measurements (if PID is used), blow counts (if split spoon samples are collected), sample recovery, depth of borehole, length of well screen, length of well casing(s), sand pack interval, well seal interval. The site investigator should identify the relative location and number.

## C.4. NON-AQUEOUS PHASE LIQUID (NAPL) SAMPLING PROCEDURES

**Responsible Personnel:** Technicians and Geologists

**Training Qualifications:**

All field personnel involved NAPL sampling, as a minimum completed OSHA 40 HOUR HAZWOPER training. Prior to NAPL sampling, all field personnel will have worked a minimum of three sites under the direct supervision of experienced personnel. Field personnel will also have experience in sampling and vapor monitoring techniques and sampling equipment decontamination.

**Materials and Equipment Necessary for Task Completion:**

A list of equipment required to sample NAPL from a monitoring well is presented below:

- Current site map detailing well locations.
- Field data book for recording site data.
- Liquid level gauging device (graduated, optical interface probe).
- Keys and tools to provide well access.
- Appropriate sample containers and labels. NAPL samples will be collected in laboratory provided 40 milliliter (ml) glass vials with plastic caps fitted with Teflon ® lined septa; all sample bottles will be laboratory sterilized and will contain the appropriate preservative, if applicable. A minimum of 10 ml is required for laboratory analysis. In the case that sufficient volume is not obtained, a swabbing technique (described below) will be used.
- Sorbent pads (required for swabbing technique).
- Teflon ® (or equivalent) bottom-loading bailer to obtain NAPL sample.
- Clean nylon or polypropylene bailer cord.
- Decontamination supplies.
- H&S supplies (tyvek, nitrile gloves, safety goggles).
- Blank chain-of-custody forms.
- Cooler and ice for sample preservation.

**Health and Safety Requirements**:

Site specific HASP must be completed and reviewed by field personnel. As a minimum, modified Level "D" attire will be worn. Individuals performing NAPL sampling are required to wear safety goggles, tyvek suit, and nitrile sampling gloves.

**Decontamination Requirements**:

During NAPL sampling activities, dedicated sampling equipment (i.e. Teflon ® bailers, nitrile gloves, and bailer cord) are utilized; thereby, eliminating decontamination requirements. The interface probe, used to record the presence of NAPL and relative thickness prior to sampling, does require decontamination between sampling locations.

All site equipment used in a multi-well capacity will be decontaminated immediately prior to initial use and between each well. Standard site decontamination procedures for the optical interface probes between wells will be performed according to the following schedule:

- Initial rinse with clean tap water to remove excess residuals.
- Scrub equipment with sponge or clean, soft cloth in a distilled water/Liquinox@ (or equivalent) solution.
- Double rinse with deionized/distilled water.

**Methodology:**

Each monitoring well to be sampled will be gauged to obtain liquid level and relative NAPL thickness immediately prior to initiation of the sampling process. Refer to SOP No. 1 for appropriate well gauging procedures. Liquid level data will be recorded in a field book.

Sampling of the NAPL will occur via two different methods: 1) direct sample or 2) swabbing.

The following sequence of procedures will be implemented for the collection of groundwater samples from monitoring wells.

1) Establish a clean work area where sampling equipment will not come in contact with the ground or any potentially contaminated surfaces.
2) Use a laboratory, pre-cleaned Teflon@ sampling bailer for each well.
3) Don an unused, clean pair of nitrile gloves.
4) Attach an appropriate length of unused, clean nylon or polypropylene cord to the designated sampling bailer.
5) Select appropriate laboratory-sterilized sample containers.
6) Slowly lower sampling bailer into well until water surface is encountered; continue to lower the sampling bailer into the standing water column to one foot below the water surface.
7) Retrieve bailer at a steady rate to avoid excess agitation.
8) Visually inspect bailed sample to ensure for relative thickness of NAPL. If sufficient volume is present (>10 ml) place a direct sample of the NAPL into the laboratory vial. If less than 10 ml of NAPL is present, use a sorbent pad to absorb the NAPL from the surface of the groundwater sample. Place is swab sample into the laboratory vial.
9) Complete and attach labels to sample containers noting sample collector and date, time, and location of sample; record same data in field book.
10) Place samples in ice-filled cooler in such a manner as to avoid breakage. Samples collected for VOC analysis will be maintained at a temperature of 4°C.
11) Discard gloves and bailer cord and move to next sample location.

**Documentation:**

All site activities should be detailed in the site investigators fieldbook. The entry shall include the date, time, weather, address, persons present on-site, and the aforementioned parameters. Only relevant observations should be recorded. The nature of the work being performed is also appropriate.

## C.5. PUMPING TESTS

**Responsible Personnel:** Hydrogeologists, Engineers and Technicians.

**Training Qualifications**: All field personnel performing pumping tests shall have completed OSHA 40-Hour training, and three days of field training. Personnel directing the pumping test shall have assisted with a minimum of three tests under the direct supervision of experienced personnel. Field personnel will have experience in operating the following field equipment: interface probe, data logger, submersible pump, related piping and fittings, flow meter and portable generator.

**Health and Safety Requirements**:

A site specific HASP must be completed and reviewed by all field personnel. Caution must be exercised in set up of electrical equipment, particularly the placement of pumps in a well which could be impacted by floating product. Other health and safety concerns include slip/trip hazards, and area traffic.

**Decontamination Requirements:**

Pump, discharge lines, hand held probes and all pressure transducers must be cleaned with Alconox and distilled water prior to installation in wells at site, and again following removal. Any water sampling activities to be incorporated during the test must be prepared and used in accordance with the Groundwater Monitoring SOP.

**Methodology**:

1) Pre-test Considerations:

Some site specific information regarding the geology and hydrogeology of the subject site is needed to determine the most appropriate type of pumping test and to estimate the reliability of the test results. Lithologic logs of the subject site will indicate whether the zone of interest is an unconsolidated formation or a bedrock formation. They should also give a strong indication as to whether the zone of interest is a water table formation, a confined formation or a leaky-confined formation, and whether any preferential (vertical or horizontal) transmissivity may be expected. Logs and/or slug test data will also provide indications as to what test yield is sustainable, and provide a rough indication of the areal extent pumping will influence. Additional pre-test considerations include any obvious positive or negative hydraulic barriers, any tidal effects, and /or any influence from other wells pumping in the area.

Often times, budget considerations and/or time limitations will necessitate the use of a monitoring well as the test pumping well. While this is generally acceptable, the well must be screened deep enough to allow design drawdown to be achieved and friction losses (well loss) in the pumping well must be taken into consideration when the test data are analyzed. A minimum of three monitoring wells in the vicinity of the test pumping well are needed to evaluate formation response. Ideally, the wells should all be at varying distances from the test pumping well and screened across the same zone.

Pumping tests are broken into two general classifications: step tests and constant rate tests. Step tests involve pumping a well at progressively higher rates, at set intervals of one or two hours per step. They are often used to determine the yield a well will sustain during a constant rate test and to evaluate well loss (frictional head loss between the screen/gravel pack and the formation). Constant rate tests are used primarily to evaluate aquifer coefficients for design of groundwater treatment systems and/or water supply purposes. In high sensitivity sites, where budgets permit, the best method is to do a step test first, to evaluate well loss and long term sustainable yield, allow 24 hours of recovery and then initiate the constant rate test.

The test duration is subject to site specific data requirements (i.e. sensitivity. required test goals, etc.) and to budget considerations. Optimally, a constant rate test will be run until all drawdowns have stabilized, and gravity drainage effects are curtailed; however, this is seldom practical due to time limitations. In most instances, an 8 hour constant rate test will be adequate, and a 24 hour test will be sufficient for higher sensitivity sites. Occasionally a 72 hour pumping test is warranted, though this is usually reserved for large scale water supply work. If there are any unexplained water level anomalies observed toward the scheduled end of a test, the test should be continued if at all possible.

The approximate test flow rate needs to be determined in advance for proper pump and discharge design selection. If it is not appropriate to perform a step test, sustainable yield can be estimated from slug test data or a brief (<30 minutes) pumping episode the day before the actual test. Generally, it is best to pump the well at as high a rate as is feasible order to obtain the greatest formation response data from the test. However, if floating product is present at or near the pumping well, drawdown needs to be limited so as not to impact uncontaminated soils below the water table. In these instances drawdown should be limited to less than 5 feet. In water table formations, if there is no concern regarding floating product, drawdown should not exceed two-thirds of the wetted screen depth due to the effects of friction loss.

If the test discharge is contaminated, it must either 1) treated prior to discharge or 2) containerized for off-site disposal. If it is to be discharged directly on- site and allowed to re-infiltrate (verses discharged to a catch basin) it must be routed sufficiently far enough from the test area as to avoid any artificial recharge effects. All appropriate discharge permits must be obtained and complied with. If discharge water is to be treated on-site, proper contaminant loading calculations for the test flow rate, approximate contaminant loading and test duration must be done in advance to insure treatment is completely effective. Any on-site treatment should also have at least one discharge effluent sample lab analyzed to document treatment effectiveness.

2) Pumping Test Set Up:

Prior to starting the test, all well measuring points (i.e. top of casing) should be clearly marked and vertically surveyed to the nearest 0.01 feet. The horizontal distance and orientation of all wells should be surveyed to the nearest 0.1 feet, and illustrated on the site base map. If there are any surface water bodies in the vicinity, a staff gauge should be set up and surveyed in to evaluate possible influences.

The preferred pump to be used for a pumping test is a submersible centrifugal pump ("Grundfos", or equivalent), run off either existing site power or a portable generator. These pumps are not explosion proof, so a conductivity probe must be tied into the pump controls to alleviate any possibility of product coming into contact with the pump. If the test pump is designed to pump total fluids (e.g. air operated double diaphragm pump, jack pumps, etc.) discharge must either be containerized, or treatment must include an oil/water separator to handle any floating product. The submersible pump should be positioned just above the bottom of the well, using a handling line to support the pumps weight.

**NOTE:** extreme care must be taken that the power cord is neither bearing any of the pumps weight, nor damaged during installation due to the potential for sever electric shock.

Discharge piping from the pump should include a flow meter (preferably with totalizer), followed by a flow adjustment valve. The flow meter should be installed in a straight section of hard piping of sufficient length to avoid meter distortion caused by turbulence (typically about 10 pipe diameters on either side of the meter). In low flow pumping tests, flow rate can be calculated by measuring the exact time required to fill a known sized container.

Ideally, groundwater levels should be static prior to starting the test, so that pumping influences alone can be readily evaluated. Water levels in all monitoring wells and/or nearby surface waters should be gauged a minimum of two times during the 24 hours prior to starting test pumping; readings should not have varied by more than 0.10 feet. Any significant precipitation events within the previous several days will usually result in noticeable water level changes (barometric changes have significant influences in confined and semi-confined formations). If there are any major water level changes that cannot be accounted for prior to test pumping, additional investigation into possible area influences (e.g. local well pumping or construction de-watering) should be conducted.

Exact water level measurements (to the nearest 0.01 feet) and exact time denotations during the test are critical to achieving accurate test results. All personnel involved with taking measurements during the test should have watches with a second hand, and they should all be calibrated to the same time. Adequate liquid level measurements can be obtained using an interface probe ("ORS", "Solinst", etc.) for those wells with floating product. In wells clear of floating product, an electric water level detector ("Solinst", "Hazco", "M-Scope", etc.) or chalked steel tape will provide accurate measurements. All non-dedicated probes must be properly decontaminated after each level reading to prevent any possibility of cross contamination between wells.

Automatic water level recorders are typically used during pumping tests to augment hand measurements and to obtain reliable early time-drawdown data. A pressure transducer allows measure of changes in groundwater levels by measuring differences in pressure experienced by the transducer. The pressure transducers are manufactured by “In-Situ” and are available with many types of data loggers. Some data loggers are capable of connecting to several transducers (Hermits) while others collected data from one transducer (Trolls and Mini-Trolls). The measured depth data for each probe is digitally stored in the data logger as depth (in feet) at a specific elapsed time. At the conclusion of the test, the data logger is brought back to the office, and the test data is down loaded into a computer for analysis.

The transducer is installed in each well to a depth several feet lower than the greatest drawdown depth anticipated. The transducer cable is secured at this depth with duct tape or cable ties attached to the well head, and the transducer is plugged into the data logger. The transducer must not be submerged deeper than the allowable operating pressure, which is noted on each transducer cable spool in PSI. Care must be taken that the transducer cable is not damaged from rough edges at the well head, and that no vehicles run over the cable. In addition, any wells with floating product require an inner PVC stilling well to be installed to prevent the transducer cable from being damaged from contact with product. The stilling well will also eliminate the need for any water level corrections for product thickness.

In terms of prioritization, transducers should be utilized in the wells closest to the pumping well and then pumping well. Wells further from the pumping well can be successfully monitored by hand, due to the reduced likelihood that early time drawdown will be critical. Despite having transducers in given wells, back up hand readings should be taken at least hourly during the first 8 hours of the test, and then at least every 3 hours, to verify the transducer levels.

After the transducers are installed in the wells, and connected to the data logger, hand measurements are taken at each well with a transducer. These levels are then entered into the data logger as initial reference points for comparison to the depths measured by the transducers. Readings from the transducers are not completely reliable until they have been emerged for at least 30 minutes, due to the effects of probe temperature equilibrium.

3) Running the Test:

Prior to starting the pumping test, the data logger must be completely formatted for that particular test, and the operator must be completely familiar with the start up sequence. If possible, the pump discharge control valve should be pre-set to the desired flow rate prior to turning on the pump. However, depending on the test pumps performance curves, minor flow rate adjustments are generally needed during the first hour or two of the test to correct for the additional head experienced by the pump due to increasing drawdown. In addition, movement of the discharge hose after the test has been started should be avoided, since any change in the elevation of the discharge will affect the pumping rate. All changes in flow rate should be recorded with the exact time noted.

A minimum of two field personnel are needed to run a pumping test, with additional personnel required for tests with high complexity. One person should be designated to turn on the pump, adjust the flow rate, check on discharge treatment, etc. The second person should be stationed at the data logger to turn it on at the exact moment the pump is turned on. The data logger will record liquid levels very rapidly during the first part of the test, dropping off logarithmically to what ever intervals are formatted (one measurement every 20 minutes is normal). When the data logger has been activated and is running, early time drawdown measurements should be taken by hand from any wells near the pumping well that do not have transducers.

Any hand monitored wells near the pumping well should be measured frequently during the first few hours of the test, with less frequent measurements during the remainder of the test. A rough rule of thumb is one measurement every half minute during the first 5 to 10 minutes, one every 3 to 5 minutes during the first hour, and one every 10 to 20 minutes for the second hour, and then each well hourly. After the test has been running for a few hours, the transducer level readings should be compared to the hand measurements for verification, or later correction.

It is essential that some data reduction be accomplished in the field, so that major water level trends are recognized during the test. At a minimum, drawdown trends from the pumping well and two of the nearest monitoring wells need to be semi-log plotted against time so that deviations indicative of boundary conditions can be discerned before pumping is ceased. This will allow decisions to be made about whether the test should go for longer than planned.

Generally, water quality samples are taken during a test for laboratory analysis of compounds of interest. These are generally taken after the first hour of pumping and just prior to pump shutdown. If the test is of more than 24 hours duration, it is advisable to get running samples during the middle of the test as well. All samples should be obtained following sampling SOP's.

At the conclusion of the test, water level recovery data should be taken. The recovery data should plot out to an approximate inverse mirror image of the drawdown curve, with feet of recovery measured from the theoretical drawdown that would have been observed if pumping had continued. Recovery data behaves as if there were a nearby well recharging the formation, following image well theory. It has the advantage that there are no variations in the curve produced by variations in pumping rate. In water table aquifers, however, the effects of formation de-watering can cause the recovery trends to be substantially different from drawdown trends. Consequently, recovery data should be used for comparison purposes only, but not relied upon as heavily as drawdown data.

1) Data Analysis:

The data produced by pumping tests are analyzed to estimate aquifer performance characteristics, such as transmissivity, conductivity and storage, which in turn are used to predict groundwater flow under various circumstances. One of the more useful analytical products is a determination of capture zone, which is widely utilized in aquifer contamination work. Capture zone (Keely & Tsang, 1983) calculations describe the radial area (down gradient and side gradient) that a pumping well will draw groundwater in from. In the case of a contamination site, this equals to that portion of the plume a given recovery well(s) will influence, at a given pumping rate(s). Aquifer coefficients determined from a pumping test can be applied to a capture zone analysis for the determination of the best recovery system for a given plume. When the recovery system is operational, capture zone calculations can then be used to evaluate the effectiveness of the system at addressing the contamination plume, what pumping rate is optimal for controlling the plume, and the need for any additional wells. It must be noted, however, that capture zone calculations are relatively simplistic, and far from absolute. Consequently, they should be used with considerable margin for safety, and employed with a large measure of common sense.

The mathematical solutions used in pumping test analysis include many assumptions typical "real world" formations violate in one or more way (e.g., "the formation is of uniform thickness and of infinite areal extent"). In addition, some of the values incorporated into typical pumping test solutions are not actually measured, but are educated estimates (e.g. porosity based on lithology, etc.). Consequently, even the most carefully designed and executed pumping tests have severe precision limitations, and the solutions should never be considered absolute. This is why groundwater flow evaluations are generally conceded to be "a mixture of science and art", and all solutions require a strong application of common sense and experience.

Many problems associated with pumping test data evaluation are due to not recognizing, and/or correcting for, deviations from the theoretical solution employed. Some of the more common errors occur due to: partial penetration effects, formation de-watering effects, casing storage effects, poor pumping well efficiency and/or the application of incorrect equations or units. Consequently, a thorough understanding of the underlying assumptions inherent to the solution employed is required before the validity of the results can be trusted. There are numerous references that describe pumping test analyses. Some of the more recommended references include: Driscoll's "Groundwater & Wells" (1986); Lohmans "Ground-water Hydraulics" USGS Professional Paper 708 (1979) and Fetter's "Applied Hydrogeology" (1980). In addition, the USGS published "Aquifer-test Design, Observation, and Data Analysis" in 1983 by Robert W. Stallman (Applications of Hydraulics, Book 3, Chapter B 1). This is an excellent, common sense, guide to pumping test set up, measurements and data analysis.

Two of the more common pumping test equations used and their applications are listed below:

1) Cooper-Jacob (1946); time-drawdown & distance-drawdown methods: Test data is plotted on semi-log paper, and the slope is used in the solution. Both solutions assume the formation is confined; however, this distinction lessens over time as drawdown becomes stabilized. Distance-drawdown has an added advantage in that it allows water level to respond from across the site to be used, which accounts for some lithologic variations.

2) Boulton (1963), modified by Neuman (1975): This solution is used for determining aquifer coefficients in water table formations, taking gravity drainage (delayed yield) effects into account. Time- drawdown data is plotted on log-log paper and two Theis type curves are matched to get early time-drawdown and late time drawdown, respectively. While this solution most closely matches typical floating product recovery work, it is difficult to apply and often subjective, due to the inherent nature of curve matching solutions.

It is usually appropriate to analyze pumping test data by more than one solution to get a range of aquifer performance values. These values can be averaged, or the most conservative value can be used, or the best fit based on experience can be presented. The computer program "Aqtesolv", produced by Geraghty & Miller, is a very useful tool for solving pumping test solutions. Data from an Insitu data logger can be imputed to the Aqtesolv, and curve matching solutions can be produced automatically, or with some adjustments.

## C.6. SLUG TESTS

**Responsible Personnel**: Hydrogeologists, Engineers, and Technicians

**Training Qualifications**:

All field personnel performing pumping tests shall have completed 40 HOUR OSHA training and 3 day field requirements. Personnel directing slug tests shall have assisted in at least 3 previous slug tests under the supervision of experienced personnel.

**Materials and Equipment Necessary for Task Completion**:

"Insitu " Hermit data logger, with one pressure transducer; interface tape or equivalent water level measuring device; "slug in" water displacement cylinder, or large bailer, 5 gallon pail, traffic cones and/or barricades, decontamination water and brush, alconox and decontamination pail.

**Health and Safety Requirements**:

A site specific HASP must be completed and reviewed by all field personnel. Caution must be exercised in test set up, particularly regarding vehicular traffic. Other concerns regard possible handling of free product, and slip/trip hazards.

**Decontamination Requirements:**

Any water level measuring probes, bailers and the water displacement cylinder must be cleaned with alconox and distilled water prior to use, and between uses at each well monitoring. Any groundwater and/or free product bailed must be disposed of in an approved manner, preferably in a properly installed, on-site holding tank.

**Methodology:**

Slug tests are utilized to obtain rough estimates of aquifer performance coefficients. They involve calculations based on the water level response of a well to the addition or subtraction of a known volume. They can be broken into two basic types of field exercises: slug-in tests and slug-out tests. As their names imply, slug-in tests involve the addition of water (volume) to the well, while slug-out tests involve the removal of water (volume). Water level response is monitored immediately following the displacement change, and for the next hour or so until the well has returned to approximately 90% of its original static level. Water level responses can be measured either rapidly by hand or with an "Insitu" Hermit data logger (or equivalent).

1) <u>Field Procedures</u>:

Exact well completion details are needed to perform slug test calculations. These include: total depth, total screened interval, depth to static water, casing diameter, screen diameter, gravel pack diameter and gravel pack interval. While these details should be documented on the well log, static water level and total depth should be field confirmed before the test. Where possible, several wells per site should be slug tested to obtain an average conductivity value for a site, or to evaluate lithologic variables across a site. Addition data comparisons are accomplished by performing both slug-in and slug-out tests on the same well, where time permits.

Slug-In Tests: The slug-in method is best accomplished by lowering a cylinder of known volume into the well, and measuring the water level response over time. The displacement volume should be sufficient to cause a several foot initial change in the water level. In the case of a typical 4 inch diameter monitoring well, a simple displacement cylinder can be constructed using a 3 inch diameter PVC casing, capped at both ends and filled with clean sand. An over all length of 5 feet provides adequate displacement volume for a typical water table well having about 10 feet of standing water. A steel eye should be bolted into one cylinder cap for attachment of a disposable lowering rope (discard lowering rope between wells to prevent any cross contamination).

If a Hermit data logger is to be used for a slug-in test, the transducer should be set in the well at least one foot below where the bottom of the displacement cylinder will rest upon insertion, but not lying on the bottom (beware of silt clogging the transducer tip). Depth to water should be measured and compared to the transducer reading for correlation. When the Hermit has been properly imputed for the slug test, the hermit should be activated and the displacement cylinder should be rapidly, but carefully, lowered into the well to below the water surface. *NOTE: Take particular care that insertion of the displacement cylinder does not damage the transducer or cable.* When activated, the Hermit will be automatically recording time and water levels, starting at 6 readings per second, then decreasing exponentially over time. If water level changes are to be taken by hand, they must be carefully obtained at least every minute. When the well has recovered to about 90% of its original static level, the test may be concluded. If the test has proceeded for an hour and not recovered to at least 90% of the original static, additional data will be of marginal value and the test may be concluded.

2) <u>Slug-out Tests</u>:

Slug-out tests are performed in the same basic manner as slug-In tests, only by removing a known volume from the subject well. In wells that recharge rapidly during slug-in tests, a slug-out test can be performed by merely resetting the Hermit and extracting the displacement cylinder. The more conventional method of performing a slug-out test is to use a single long hand bailer to remove a known volume of water from the well. Typical bailers used for 4 inch diameter monitoring wells are either long steel bailers (similar to those often used by drillers to develop monitoring wells) or 2 Lexan sample bailers joined end to end to form one single long bailer. The bailer is lowered into the well prior to starting the Hermit, and the slight water level rise from the bailer is allowed to stabilize back to static. The Hermit is then activated, and the bailer is rapidly removed from the well, thereby creating the instantaneous. The test is run to 90% recovery, or one hour, like the slug-in test. If the bailed water is contaminated, it must be disposed of properly via either storage in an on site holding tank or on-site treatment with a portable carbon treatment container.

The validity of slug test values are highly field dependant. Some of the more common field oriented problems arise from:

a) Subject wells are not adequately developed prior to testing.
b) Formation slough occurred during drilling, so gravel pack volume is underestimated.
c) Water displacement is not instantaneous due to the bailer leaking during extraction.
d) The pressure transducer is jarred during water displacement.
e) Water level changes are too rapid to get accurate measurements.

3) Data Analysis:

Field data from slug tests can be analyzed by hand or using "Geraghty & Millers" Aqtesolv computer program. If the field data was taken with the Hermit, the data can be transferred to Aqtesolv for analysis, saving considerable time over hand analysis. There are four well recognized analytical methodologies general employed. These methods and their assumptions are listed below:

| Application | Hvorslev | Bouwer & Rice | Cooper | Nguygen-Pinder |
|---|---|---|---|---|
| Confined Fm. | **X** | **X** | **X** | **X** |
| Unconfined Fm. | **X** | **X** | | **X** |
| Screened across water level | | **X** | | |
| Accounts for partial penetration | **X** | **X** | | **X** |
| Specific storage >0 | | | **X** | **X** |
| Allows for anisotropy | **X** | | | |
| Assumes infinite borehole storage | **X** | **X** | **X** | **X** |

As illustrated on the chart above, slug tests performed in water table formations can be solved using either Hvorslev or Bouwer & Rice methods. The Bouwer & Rice method has the advantage of accounting for screening across the water table, while the Hvorslev method allows for anisotropy. Confined formation slug tests can be analyzed by any of the four methods, though the Cooper method is most often used. It is often beneficial to solve slug tests by more than one method to evaluate possible conductivity ranges.

It must be stressed that slug test data is very approximate and limited in its accuracy. It is generally conceded that conductivity' values derived from slug tests are usually within an order of magnitude of the real conductivity, and therefore are only approximations. Consequently, any judgments based on slug test values must be used with extreme caution and incorporate a large measure of common sense and experience.